6-2016

Pleistocene-Holocene Variation of Vegetation Pattern in Upper Great Lakes Region

Karuna Paudel
Department of Geography and Planning, karunapaudel@gmail.com

Pleistocene- Holocene Variation of Vegetation Pattern in Upper Great Lakes Region

by

Karuna Paudel

A Thesis

Submitted to Graduate Faculty of

St Cloud State University

In Partial Fulfillment of the Requirements

for the Degree of

Master of Science

in Geographic Information Science

June, 2016

Thesis Committee:
Mikhail Blinnikov, Chairperson

Jeffrey Torguson,
Mark P Muñiz

Abstract

Our understanding of how the first people came to North America is still incomplete. The most common idea is that the earliest people have traveled the ice-free corridor between the Laurentide ice sheet and the Cordilleran ice sheet at around 12,000 ^{14}C yrs BP. These early people are recognized as great hunters who followed mammoth and other megafauna which supplied most of their food needs. After the extinction of the mammoth these early humans may have switched to hunting caribou (Rangifer sp.) and other smaller species. Caribou traveled in herds which made them easier to hunt and also provided hides to make warm winter clothing. In this work, we attempt to trace presumed caribou habitat in the post-glacial North America by tracking open spruce-sedge forest ecosystem which is postulated to have been the prime habitat for caribou. We produced series of vegetation maps for a portion of north-central North America from the time when the earliest people entered North America to the time period when the whole of ice sheet drained completely to the Hudson Bay i.e. from 12,000 ^{14}C yrs. BP to 8,000 ^{14}C yrs. BP. We used existing pollen records in the Neotoma database with additional records from the literature centered on Minnesota and Wisconsin. The caribou vegetation suitability mapping from point data was accomplished using IDW and cluster analysis. Using our maps, one can locate most optimal future sites for the archaeological analysis of possible caribou kills and/or earliest human habitat in north-central North America.

Acknowledgements

I am very thankful to my supervisor, Mikhail S. Blinnikov, for guiding me from the start to completion of my thesis. I also appreciate valuable suggestions from my other committee members, Jeffery Torguson and Mark P Muñiz. I am indebted to Simon Gosling and Jack Williams from University of Wisconsin, Madison for providing me with necessary information regarding the usage of Neotoma database. I would also like to show my gratitude to Tom Oien, for providing me with the software required for analysis of data. I am grateful to David Wall during the initial stage of the project, with his feedback upon the literature review. Finally, I would like to thank all of my friends for helping me while I was working with my thesis.

Table of Contents

List of Tables

List of Figures

Chapter I: INTRODUCTION

This research seeks to reconstruct the paleo-environment for the period of 15000-8000 ^{14}C yrs. BP (radiocarbon years before present) for the upper Midwest region of North America with an emphasis on tracking habitat well suited for *Rangifer tarandus spp* (Woodland and Barren ground caribou) in order to predict the best times and places that were ideal for caribou to thrive in the past. Archaeologists have hypothesized different scenarios for the initial peopling of Minnesota based on previous pollen studies and explanations derived from scant observations of Caribou utilization by paleo hunters in the region of the Midwestern states. However, there has not been a cohesive, empirically based model yet developed that identifies the timing and location of optimal habitats for caribou during the Pleistocene-Holocene transition and research presented here aims to achieve this end.

The late Pleistocene is associated with emergence of humans as dominant and efficient predators associated with extinction of many megafauna (large) mammals, for example, mammoth (Graham and Ernest L, 1984). As Caribou moved in herds, their highly diverse presence i.e. different summer and winter forage, protected them from being overkilled and getting extinct. Later, as other species of megafauna got extinct during the late Pleistocene to the Holocene transition, Caribou along with other surviving species were able to invade newly formed communities and expand their population in size. Hence, this study is clearly based on a series of observations and established hypotheses that i) the ice-free passageway opened for the early Paleoindians between 13,000 ^{14}C yrs. BP and 12,000 ^{14}C yrs. BP and ii) Paleoindians in the area were big game hunters that would probably have selected caribou as a prey species of choice because of its herding tendencies combined with its extremely warm fur. Also, 15,000 ^{14}C yrs. BP represents the time when early humans known as Paleo-Indians started to move through the open passageway between the Cordilleran and Laurentide ice sheets from Eastern Beringia (Haynes Jr., 2005). Meanwhile, 8,000 ^{14}C yrs. BP represents the time when the last remnants of the ice sheet were gone from the Hudson Bay. Hence we use the time interval from 16,000 ^{14}C yrs. BP to 8,000 ^{14}C yrs. BP

Clovis and Pre-Clovis Culture

The groups of people in North America at the end of the Pleistocene are referred to as the Paleoindians and they comprise the earliest yet recognized cultures in the New World (Lepper, 1999). These groups presumably preyed on diverse megafauna (animals >44kg) and had sophisticated technology (based on stone, bone, antler, wood etc.) and wide ranging mobility strategies. Currently, the earliest recognized culture, the Clovis culture, is dated between 11,200 and 10,700 ^{14}C yrs. BP and is recognized by a distinctive lithic tool technology and association with extinct forms of megafauna(mammoth, mastodon, camel) (Fieldel, 1999). Other Paleoindian cultures followed Clovis, but differed in their standing tool technology and diagnostic weaponry, however, an emphasis on hunting large game remained with forms of bison and deer becoming the dominant prey species where they each occurred (Theler and Boszhardt, 2003). There is some debate over the timing for the end of the Paleoindian period due to a gradual shift away from the previous lifeways that were replaced by a series of adaptive strategies and technologies collectively referred to as the Archaic tradition. However, most archaeologists would agree that after 8,000 ^{14}C yrs. BP the Paleoindian period was over in the Midwest (Lepper, 1999). The hypothesis addressed in the research originated primarily form logical expectations archaeologists developed about what early Paleoindians would hunt in the area, given analogous adaptive strategies to those observed on the Great Plains and Great Lakes Region. Caribou were in all probability a major component of the diet for these late Paleoindian hunters.

Deglaciation

This study is focused temporally on the timed deglaciation sequence of ice retreat and post - glacial environmental succession. As reviewed by Haynes (2000), who compared the record of archeological and paleo lakes, some interesting theories have been suggested. One theory states that the large amount of retreat between Laurentide ice sheets occurred uninterrupted between 13,000 and 12,000 ^{14}C yrs. BP (Haynes Jr, 2005) with the inception of Lake Agassiz around 11,700 ^{14}C yrs. BP. At first the ice-free corridor, which opened up around 12,000 ^{14}C yrs. BP, could have been transgressed by humans provided that the environmental conditions such as muskeg, runoff, catastrophic floods and wind chill factors would have allowed it. As a recently opened corridor, it would have been formidable environment for people to penetrate, one characterized by proglacial lakes, ever changing drainages, as well as stagnant ice and hummocky ground moraine. But eventually the muskeg, lake and flood water would have given way to successive vegetation which evidently gave a way for humans to settle down as they were big game hunters.

Lake Agassiz and Younger Drays

Research by Teller et al. (2005) has refined the timing of deglaciation as well as the chronological sequence of development and drainage for glacial Lake Agassiz. At its greatest extent, Lake Agassiz had an approximate area of 134,000 km^2 and drained to the Mississippi system at first, but eventually rapidly draining to the Atlantic Ocean via the Great Lakes and Saint Lawrence Valley about 10,000 ^{14}C yrs. BP. The cold event (Younger Dryas) that followed after that lasted from 10,000-9500 ^{14}C yrs. BP (Teller et al., 2005). Hence, this period of the receding of the glacier, the formation of Lake Agassiz, and the movement of freshwater to the Hudson Bay is a significant event in vegetation and climate change during those years. This event has been crucial for determining when the landscape opened up for human occupation and also in characterizing the nature of the landscape as it was affected by the glacial lake outflow.

Pollen Data

Pollen analysis is a general term embracing the study of a variety of plant microfossils of which pollen grains and spores are the most important. Since the pioneering work of Von Post in Scandinavia, the analysis of pollen spores derived from higher land plants has become the most widely used technique for Quaternary ecology (Von, 1946). This is because these particles are well represented in most accumulating sediments, and their wide dispersal provides a broad picture of surrounding vegetation and their intricate and distinctive patterning allows identification to parent plants at a reasonable taxonomic level (usually family or genus). By predicting the way landscape patterns are reflected in the pollen records, simulation models can improve research design and lead to more detailed and spatially precise records of the past vegetation (Davis, 2000). From early studies, broad regional vegetation–climate relationships were established from pollen in north-west Europe, northeastern North America, and elsewhere, providing an important relative dating tool for archeological and other events. The value of pollen analysis is more marked because the radiocarbon chronology of Paleoindian archaeological sites in Minnesota is incredibly poor. Mullholland et al. (1997) noted that in many cases throughout Minnesota and southwestern Ontario, problematic radiocarbon dates are associated with charcoal collected from archaeological sites, but generally not with organic material collected from pollen cores. Sources of erroneous dates may be a combination of organic degradation from acidic conifer forest soils combined with mixing of younger charcoal onto older deposits by rodents and tree throw of shallow soils. Mullholland et al (1997) concluded that by the time Clovis people appeared in North America (~11,200 ^{14}C yrs. BP. BP), all of Minnesota was free of ice and early human groups could have occupied the area. However this doesn't automatically mean the area (north eastern Minnesota) was hospitable in terms of climate or faunal resources. Tundra is certainly capable of supporting the animal population often hypothesized as being the basis for Paleoindian subsistence. However, these early settlers needed suitable prey to persists, yet few direct studies exist proving their diet. Also, pollen data serves to refine interpretations from pollen analysis or provide evidence because of the abundance of sites available for preservation in case the Great Lakes Region. At most inferences, pollen data has served to reconstruct not just the vegetation sequence that can be found from the cores but helped in the reconstruction of climate in the region.

Climate of Holocene and Pollen data Usage

Quaternary climatologists do not yet know all the details of the Holocene climatic change at the local to regional scale at which climate affects the vegetation recorded by one to several pollen diagrams. But evidence independent of pollen data is accumulating that shows 1) regional patterns in climatic changes on all time scales, 2) temperature and moisture conditions changing independently, 3) major changes in seasonality during the late-Quaternary, and 4) late-Holocene climatic patterns that are different from early Holocene patterns (Crowley, 2000). Spatial patterns are evident in the sea-surface temperature map for 16,000 ^{14}C yrs. BP just as they are in monthly and decadal anomaly maps. On all time scales, global climatic changes, whether they be abrupt or gradual, have been expressed differently in different regions, because they induced spatial patterns in temperature, precipitation, and other meteorological variables (Yu, 2000) . Global changes that are gradual can induce abrupt changes in certain regions, and abrupt global changes can induce gradual changes locally or regionally (Bartlein, et al., 2011).

Lake level data from the tropics and various continents indicate changes in regional water budgets and provide evidence for changes in the combination of temperature and moisture conditions in many regions. The work of Kutzbach, Harrison and Behl, (1998) has demonstrated the potential importance of the orbital induced seasonal variation in solar radiation as a forcing function for climatic change during the past 20,000 yrs. BP. In the Northern Hemisphere, the seasonal radiation contrast increased until between 10,000 and 7,000 ^{14}C yrs. BP and then decreased.

The solar radiation affected North American climates unlike Asia and Africa but the long-term retreat of the Laurentide ice sheet led to a more complicated climatic response than the response in tropical regions(Ritchie, Cwynar and Spear, 1983). At its maximum extent at 16,000 ^{14}C yrs. BP the Laurentide ice sheet not only was a highly reflective surface to solar radiation but also acted as an orographic barrier to atmospheric circulation (Bryson and Wendland, 1967). As the ice sheet retreated, the climatic impact of its role as an orographic barrier decreased faster than its role as a reflective surface. The climatic consequences were therefore complex but are beginning to be understood. Even without knowing the details, one can use meteorological theory along with the history of ice sheet retreat in order to describe some of the probable complexity in the climate changes in eastern North America since the last glacial maximum at 16,000 ^{14}C yrs. BP.

When the temperature field across a sub continental area is considered for some date (e.g. 10-18,000 yrs. B.P), three features require description: 1) the mean temperature for the field, 2) the extreme temperatures and the direction of the main temperature gradient (i.e. the two sites with the highest and lowest temperature should be located), and 3) the regions within the field with steeper than average (or flatter than average) thermal gradients and the orientation of these steep (or flat) gradients within the study area (Bartlein, et al., 2011). The position and orientation of the thermal gradients are important to meteorological dynamics because steep temperature gradients define the location of mean frontal positions and hence the regions in which storms form and track and hence mark the boundaries between contrasting air masses (Bartlein, et al., 2011).

Vegetation and Climate Response of North America during Holocene

Climate from the past provide information about the patterns to be expected in the future. Hence, for this study we need to identify the climate alongside the vegetation that influence each other.

When the vegetation responded to increasing temperatures after a postulated temperature minimum during full glacial times (see Peterson et al. (1979) for the evidence from 16,000 ^{14}C yrs. BP), the mean temperature for eastern North America also increased and the difference in temperatures between the northern and southern ends of the continent change. The magnitude of the temperature changes in the north and south were not the same, but radiation differences guarantee a north to south temperature contrast at all times. The presence and slow retreat of the Laurentide ice sheet from 16,000 to 4,000 ^{14}Cyrs. BP also guarantees that certain regions warmed faster than others. Within this frame work of change, if one region warmed faster than another region, then the position and orientation of the steep thermal gradients would change. The increasing temperatures would change the characteristics of the air masses, and the changing location of the thermal gradients would necessitate changes in the location of storm tracks and in the frequency and duration of the air masses. Rainfall patterns and magnitude would also be affected by the increasing temperatures, the changes in the air masses, and the changes in the thermal gradients (Peterson et. al., 1979). In light of all these changes and their varying effects, one would label any model for Holocene climatic change simplistic if it emphasizes mere increases and decreases in mean annual temperature and implies a similar timing and magnitude for this increase and decrease at all sites across North America.

The many interacting elements of the late-Quaternary climatic change are quite sufficient to allow for the observed crisscrossing patterns and differential rates of range-boundary movements that Davis (1978, 1981a, 1981b) and Birks (1981) have interpreted as evidence for migration lags and non-equilibrium distributions. Under the complex nature of past climatic changes, individualistic behavior by the different species should be expected (Chapin and Shaver, 1985). Therefore, there are high inferences of vegetational sequence changes when we couple it with the receding ice-sheet.

Caribou and Paleontological record

There are many references in the literature to prehistoric reindeer in Europe and Asia a species of Eurasian origin (e.g. Osborn, 1910). The compilation was of the prehistoric North American species where there were only eight Canadian fossil specimens from the Yukon Territory (Keslall, 1968; Banfield, 1962). Banfield (1962) suggested that the caribou reached as far east as Alaska before the penultimate glaciation and have been present in North America continuously since that time and through Wisconsin glaciation (last 120,000 yrs. BP.). Their presence ranged from tundra belt across the edge of the ice sheet from New Jersey to mountainous regions in the southwest- New Mexico and Nevada an extent southward into forested regions as they do today. And after glaciation, caribou undoubtedly followed the retreating ice sheet to the several localities where present-day populations are found (Kelsall, 1968).

In 1964, and revised in 1971, Karl Butzer applied ecological studies of carrying capacity to predict preferred zones of occupation for early human populations around the world which led James Fittings to use his model to interpret early Paleoindian adaptive strategies in the Great Lakes Region. Excavations at the Holcombe Beach site in the southeastern Michigan by James Fittings and colleagues (Fittings, DeVisscher, and Wahla, 1966) identified burnt caribou bones in a hearth associated with an early cultural group, named the 'Holocombe cultural complex' based on artifacts recovered from the site. James Fittings, (1968) applied Butzer's (1971)models for predicting how early Paleoindians would have practiced different adaptive strategies in different part of the Great Lakes Region based on response to specific local environments and rates of change for those environments.

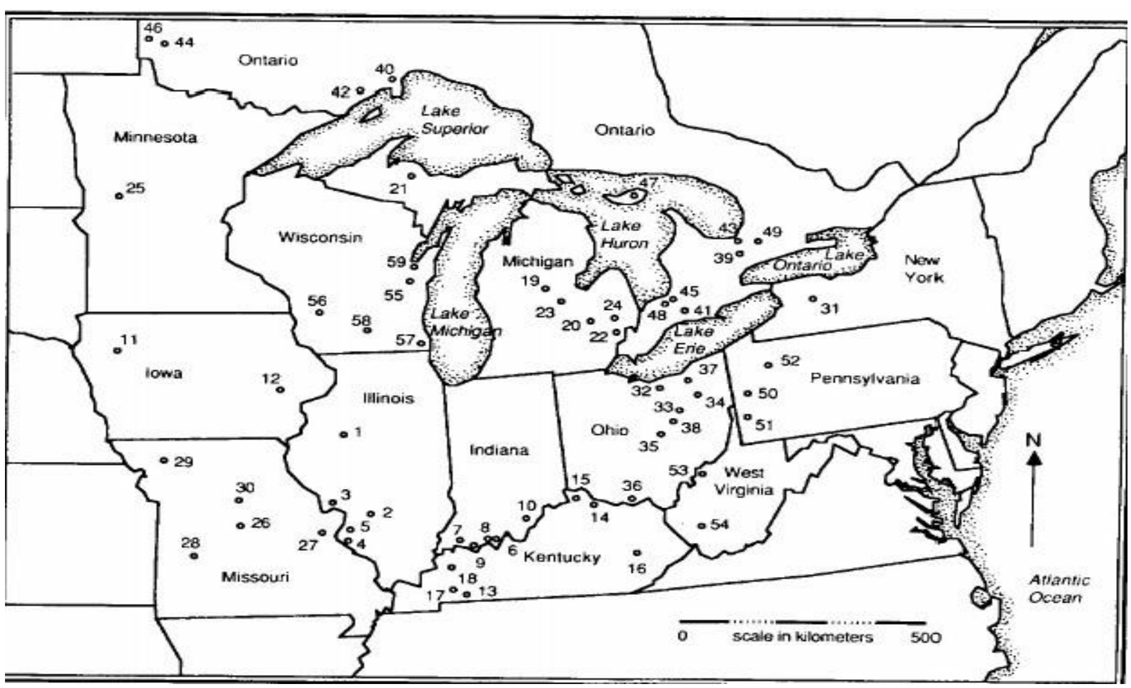


Figure 1.1
Map of late Pleistocene/early Holocene archaeological sites in midcontinental North America (Refer to table 1.1 for site information) (Lepper, 1999)

Table 1.1
Principal late Pleistocene/ early Holocene Clovis and Pre-Clovis sties in Michigan North America

19	*Barnes(Voss,1977)*	*22*	*Holcombe(Fittings et al. , 1966)*
20	*Gainey (Simons et. al., 1984)*	*23*	*Leavitt(Simons et al. , 1987)*
21	*Gorto(Buckmaster and Pacquette, 1988)*	*24*	*Rappuhn (Wittry, 1965)*

Source: (Lepper, 1999)

More recently, excavations at the Udora site in southern Ontario (Strock and Speiss, 1994) also identified caribou with fox and hare as early Paleoindian prey species that would have been utilized by a culture slightly older than the Holcombe Beach occupants. This site is dated between 10,000 to 10,500 ^{14}C yrs. BP. These data supporting Fittings original interpretation of Paleoindian hunters selecting caribou as well as smaller tundra fauna, is only the second well documented example in the Great Lakes region.

Habitat Range of Caribou

Caribou ranges over two biomes: Tundra and Taiga. Tundra means the treeless areas where the subsoil is permanently frozen and Taiga includes the transition section of boreal forest. Both of these vegetation are circumpolar except where interrupted by sea. A knowledge of both biomes is mandatory to an understanding of the ecology of caribou.

Presently, tundra biome ranges from Ungava region of Canada to Alaska in North America and from Kamchatka to Lapland in Eurasia and also covers intervening high latitude islands between the continents. They include: mosses, lichens, sedges, grasses, a few woody shrubs and a variety of herbaceous flowering plants. It usually provides summer range for barren-ground caribou and winter range for some. The dominant physical feature called permafrost causes development of prominent landscape features such as ice mounds, pingos extensive polygon formations, and other types of patterned group which has a profound restrictive influence on water drainage and plant growth, and thus effects the ecology of virtually all resident animals (Kelsall, 1968).

Taiga provides the main winter range for barren-ground caribou while some caribou remain on the tundra the year round. It is a predominantly coniferous forest, often tall and close-growing in the south and progressively smaller and more open-growing towards tree-line. At its northern extreme it gives way to open lichen woodland which finally merges with the tundra (Rowe, 1959). White and black spruce are the dominant tree species and other locally are tamarack and jack pine while birch and poplars are the commonest deciduous trees.

Food Habitat and Range Studies of Caribou

Caribou feed almost exclusively by grazing. They seldom nip off woody twigs and stems as deer and moose do habitually. At all seasons, low ground vegetation is their preference. They make little use of occasional stands of tall willow and birch on their summer range. As fresh green vegetation develops in spring, caribou seek it out in the areas in which it is the most abundant. Following the period of rapid plant growth in spring and early summer, caribou become less particular in their feeding behavior (Kelsall, 1968). The consumption of sedges, grasses and the leaves of willows and birches diminishes as the vegetation becomes more mature and tough. Miscellaneous summer and autumn foods are eaten including berries (Rowe, 1959). Once annual green vegetation is frosted and dry and snow falls caribou diets become much more limited to various forms of lichens (Rowe, 1959).

Lichens are frequently eaten except during few dry periods. The fungi are mostly sought after they become abundantly available in summer and winter foods include a good many items in addition to lichens (Shelford, 1963). As summarized by Kelsall (1968), that combines their summer and winter forage lichen comprises 50 percent of its food habit, *Vaccunium uliginosum, V. vitis-Idaea* (two species from Ericaceae family)*, Carex,* and *Salix* together make up 46 percent of all occurrences. Additional items in descending order of frequency are *Betula* (1.3%), *Arctostaphylos* (1.6%), mosses (1.1%), *Empetrum* (1.1%), *Juniperus* (0.6%), grasses (0.3%), *Abies* (0.3%), *Picea* (0.1%) and *Saxifraga* (0.1%). Some of the plants identified grow as an almost inseparable part of lichen carpet and their ingestion is incidental to the gathering of major food but some of the sedges are deliberately sought which have small green shoots in winter. Hence, it can be concluded that Gramineae-Cyperaceae*, Salix, Betula* and *Abies* are the most important foods in both seasons, while *Picea and* Ericaceae are mostly sought winter foods.

Vegetation Succession during Pleistocene-Holocene

Cushing (1965, 1967) based his post-glacial successional sequence primarily on pollen core sites located along the eastern third of the Minnesota and recognized a *Compositae-Cyperaceae* basal zone for the entire state. Following this, he and others (e.g., Watts, 1967), noted a shift to a *Picea-Larix* assemblage zone in the south around 13,000 ^{14}C yrs. BP and to a *Betula-Picea* zone in the north a little after 11,000 ^{14}C yrs. BP. Between 11,000 and 10,000 ^{14}C yrs BP in the south, the *Picea-Larix* zone shifted briefly to *Betula-Abies* before transitioning to *Pinus-Pteridium* by 9,500 ^{14}C yrs. BP. In the northeastern region(southern Arrowhead), Cushing identified the

Betula-Picea zone transitioning briefly to *Picea-Larix* before becoming *Picea-Pinus,* but in the northernmost sample site the brief *Picea-Larix* zone is absent from the sequence.

Late glacial pollen sequences from southern New England recorded a long interval of tundra persisting until about 10,000 ^{14}C yrs. BP. An open spruce woodland developed by 8,500 ^{14}C yrs. BP. During the intervening period (10,000-8,500 ^{14}C yrs. BP) the vegetation may have resembled park-tundra or alternatively, spruce-oak woodland similar to modern vegetation near the prairie in Manitoba. In the Great Lakes region, there was only a narrow belt of tundra vegetation, succeeded by woodland and forest which may have resembled modern vegetation near the prairie margin, or modern vegetation of the boreal forest and forest-tundra to the north.

The boreal spruce forest apparently gave way to pine dominated forest with varied pace of transformation and trees at the end of Pleistocene through the northern and eastern United States (Wright, 1970). In southern and western part of the states, spruce was immediately replaced by birch and alder and then by other hardwoods and the low pine pollen values reflect distant transport of pollen from the northeast (Wright, 1968). This is supported through a site Kirchner Marsh in southeastern Minnesota where the spruce forest was replaced abruptly by birch, alder, and temperate hardwoods before pine entered the region for a short period during 8,000 ^{14}C yrs. BP (Wright, 1970). At Wolf Creek in central Minnesota, pine arrived from the east virtually at the moment when spruce declined. At Lake of the Clouds in north- eastern Minnesota, spruce forest had succeeded tundra about 8,000 ^{14}C yrs. BP. ago, but simultaneously pine and temperate hardwoods appeared in quantity. The spruce and hardwood components then declined and about 7,500 ^{14}C yrs. BP. ago pine increased to dominance during the following 400 yrs. BP (Wright, 1968).

A study by Jacobson, Thompson and Grimm, (1987) outline how each species changed in timed sequence over North America. It suggests that species abundances changed significantly within every 2,000 year period with continuous yet varied rate of change. The particular time period for where site across all regions show synchronicity and also subject to broad atmospheric circulation are 11.5, 10.3 and 8 ^{14}C yrs. BP (Mix and Ruddiman, 1985). Also, Mix and Ruddiman (1985) suggest the most abrupt change in ice volume occurred between 12 and 10 ^{14}C yrs. BP. One specific change was the shifting in orientation of pine from north-south orientation to east-west orientation of the Great lakes region. And, pollen assemblages in the modern surface sediments from Canada display geographical correlation with modern vegetation there (Graumlich and Davis, 1993).

As the excavations from Holcombe Beach site by James Fittings and colleagues(Fittings et. al., 1966) and Udora site in southern Ontario by Storck and Speiss(1994) identified burnt caribou bones in a hearth associated with early cultural group called 'Holcombe cultural complex' and slightly older than Holcombe Beach occupants respectively based on artifacts recovered from the site. Also research by James Teller (Teller 1987, 2001; Teller et al., 2005) has refined the timing of deglaciation for Minnesota and the Great Lakes Region as well as the chronological sequence of development and drainage for glacial Lake Agassiz. This work has been crucial in establishing both the timing of when the landscape opened up for human occupation and also in characterizing the nature of that landscape as it was affected by the glacial lake outflow.

Work by Patrick Julig (1994) at the Cummins site in Thunder Bay, Ontario dealt with reconstructing the local paleoenvironments as a means of establishing the earliest possible date for human occupation of the site. Julig (1994) noted that Thunder Bay was clear of glacial ice by around 11,000 14C yrs. B.P., with the spruce-dominated boreal forest giving way to pine by 9,400 14C yrs. B.P. Also Storck (1988), noted that “If this species [caribou] was adapted to the open spruce forest, it is tempting to view the destruction of that forest as causally to the disappearance of the Early Paleo-Indian lifeway. Unfortunately the data that would document this, or suggest alternative hypotheses, simply do not exist” (Storck, 1988). Storck goes on to identify the need for radiocarbon dated archaeological sites with faunal and floral data necessary to reconstruct the human use of the paleo-environment. Also, Pollen assemblages in the modern surface sediments from Canada display geographical correlation with modern vegetation there (Graumlich and Davis, 1993).

Hence, we use pollen data form Pleistocene- Holocene in the great lakes region to identify the spatial distribution of the earliest artifacts sites found in the Great Lakes region combining with the dated sequence of glacial retreat.

Chapter II: METHODOLOGY

The methods used for this study stemmed from to the need to understand where the prime caribou habitat was located in the past using pollen data. The main source of the latter was the Neotoma online database (Neotomadb.org, 2015). The extent of the ice sheet and Lake Agassiz and other proglacial lakes used data layers of Dyke and Robertson (2003). The seasonal food preferences and nutritional values for caribou diet are known from Shelford's (1963) classic study of North American mammal ecology that specified several characteristic plant species of the caribou diet. The following comprise the highest cumulative percent of caribou diet throughout the widest range of seasons: the fruticose (tall growth) tundra lichens of the order Lecanorales, specifically *Cladonia alpestris* and *Cladina rangiferina (L.) Nyl;* heath plants Gramineae- Cyperaceae*, Salix, Betula* and *Abies* (Kelsall, 1968).

Also, one of the theories that can be illustrated through the interpolated diagrams would be the Plaid vs Stripes theory stated in Jacobson et al. (1987), where during the late Pleistocene there is a postulated north-south mixed gradient of species and during the Holocene it becomes an east-west orientation. During the longitudinal orientation there was more heterogeneous orientation of floral communities and faunal communities had to move a lot. But during latitudinal orientation, there was homogenous vegetation because of which faunal communities also didn't have to move a lot. As Graham, Ernest and Lundelius, (1967) describe, the caribou managed to survive, while other large species like mammoth and mastodons went extinct, probably because of the caribou adaptations to particular post-glacial habitat and significantly different ecologies and their ability to rapidly adapt to new and shifting vegetational communities. Hence, their presence during the Holocene which is already in east-west orientation is homogenous and similar to present day floral communities. Therefore, the habitat upon which the present day caribou survives to describe the prime and favorable caribou habitat was used.

Based on the data from Kelsall (1968), Shelford (1963), Cushing (1965, 1967) and Watts (1967) and human behavioral expectations based on the work done by Butzer (1971), Fittings (1968), Storck and Speiss (1994) and Mulholland et al. (1997), it was expected that the plants most required by caribou would occur within the late Pleistocene-early Holocene *Picea*-Cyperaeae paleo environment (Mulholland et al.'s zones one and two) and that this zone would shift in space through time. Based on the previous ecological studies, for the idealized caribou habitat selected is *Betula spp, Cyperaceae,* Ericaceae*, Picea spp., Salix spp.* and *Sphagnum spp.* as primary indicators, with *Pinus* and *Quercus* indicating the shift away from the spruce-sedge parkland to a more closed canopy coniferous-deciduous forest that typifies the area today. It was recognized that caribou can live within the modern mixed coniferous zone as woodland caribou could be still seen in the Boundary Waters Canoe Area Wilderness as recently as 1920s-30s (Clayton, 2010, personal communication) . However, the carrying capacity of the idealized late Pleistocene spruce-sedge caribou habitat chosen to model should have been substantially greater than the closed-canopy coniferous deciduous forest that followed. Furthermore, the shift from the former to the latter would almost certainly have necessitated a significant change to the adaptive strategies of the Paleoindian's living in the Great Lakes region during that time.

As the pollen assemblage shows geographical correlation with the modern vegetation, we decided to use the pollen data that could help us describe the past relationship between the geographical events and vegetation. Hence, comprehensive neotomadb.org database was decided to use as primary pollen data source. The benefit of using this database is that it quickly and accurately provides the mapped location and references for each sample, the chronological control for each sample is standardized across all samples (which avoids problems with correlating radiocarbon dates from one study with calendar dates used in another study), and most importantly it provides raw frequency counts (NISP) for all samples recorded in the core rather than summary percentage data that is graphed as figure in many original publications.

The Neotoma paleoecology database can be queried for all sites with pollen data around the world. As concerned with the sites along the Great Lakes region, each site were queried looking at the record only with radiocarbon years and chronologies no older than 18,000 ^{14}C yrs. BP. and not younger than 5,000 ^{14}C yrs. BP as the dates-ranges was not sure during that time. A total of 255 sites were returned where each of the sites were evaluated again to see if they have chronologies that was going to be used i.e. from 8,000-16,000 ^{14}C yrs. BP which led to discard some of the sites resulting in a total of 165 sites shown in figure 2.1 and table 2.1. The goal was to create a broad coverage of the region with samples that came from lakes likely to preserve steady deposition of late Pleistocene-early Holocene pollen and that had good radiometric control. Thus most sites were included by virtue of their scattered geographic locations. Using the criteria above 165 sites were used in the analysis.

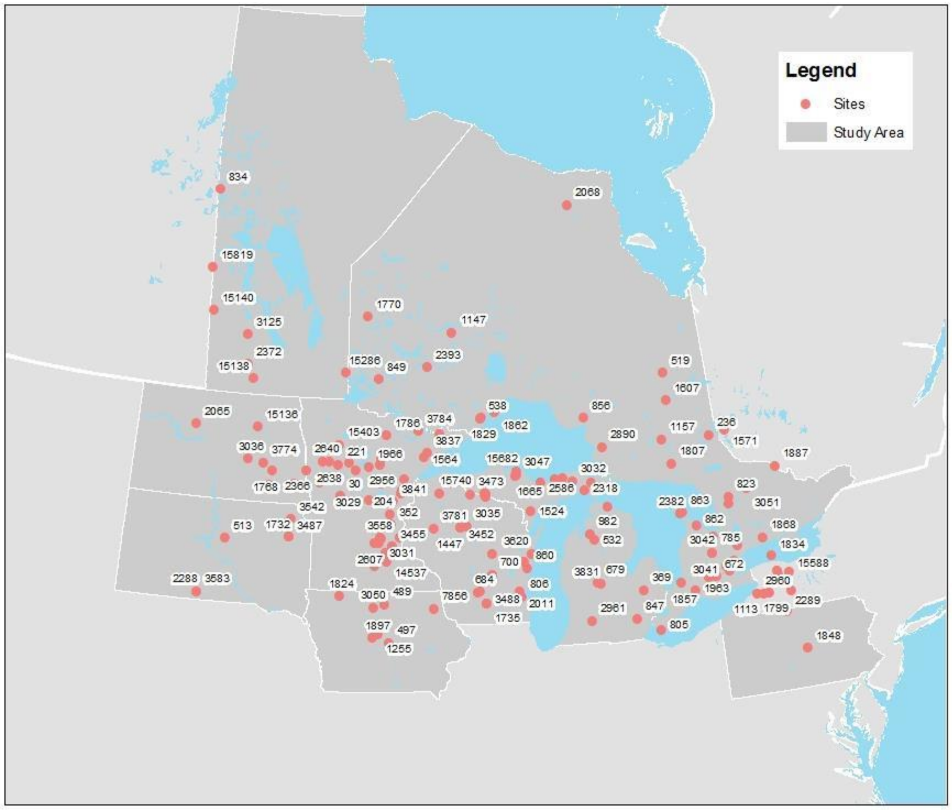


Figure 2.1
Map showing the study area and the location of pollen sites used

Table 2.1
Table showing the location, Oldest Age and Youngest Age of the sites used in the study

Site	Name	Age Oldest ^{14}C years	Age Youngest ^{14}C years	Latitude, decimal	Longitude, decimal
30	Almora Lake	13178	4060	46.206111	-95.293611
204	Andree Bog	13213	10156	45.725	-93.25
221	Axe Lake	11291	-17	47.123935	-95.397205
236	Baseball Bog	12454	-21	47.23	-79.78
352	Cedar Bog	12977	-10	45.411111	-93.197222
369	Chippewa Bog	11502	727	43.123889	-83.241111
489	Clear Lake	15394	-30	43.12507	-93.42973
497	Colo Marsh	16048	0	42.02	-93.27
513	Cottonwood Lake	13518	-21	44.835435	-99.90806
519	Crates Lake	13858	0	49.183333	-81.266667
522	Creditview Wetland	16417	10183	43.6	-79.6
532	Cub Lake	10579	23	44.7	-84.958333
538	Cummins Pond	10438	4588	48.4075	-89.346667
672	Decoy Lake	13592	40	43.233333	-80.366667
679	Demont Lake	13338	0	43.48	-85
684	Devils Lake	14342	-4	43.4178	-89.73205
700	Disterhaft Farm Bog	16484	658	43.916944	-89.166944
785	Edward Lake	18555	0	44.37	-80.25
805	Lake Erie	18778	-11	41.92	-82.76
806	Ernst Brother's Pit	15926	8443	43.233056	-88.041944
823	Fawn Lake (CA: Ontario)	12757	-30	45.41	-79.39
834	Beaverhouse Lake	10200	-26	54.742222	-101.681667
847	Frains Lake	20836	0	42.33	-83.63
849	Hayes Lake	13113	100	49.583333	-93.75
856	Furnival Lake	9167	-28	48.21	-84.93
860	Gass Lake	18876	0	44.05	-87.733333
862	Georgian Bay, Lake Huron	13338	-18	44.74	-80.86
863	Georgian Bay,Lake Huron	13854	529	45.17	-81.32
982	Green Lake	15066	254	44.883333	-85.116667
1002	Hams Lake	13227	-31	43.236667	-80.413333
1004	Hansen Marsh	16689	-15	43.439585	-89.670815
1110	Horseshoe Lake	15388	8989	47.322222	-53.133333
1113	Houghton Bog	13758	-16	42.541667	-78.670278
1147	Indian Lake	11115	5863	50.916667	-90.45

Table 2.1 continued

Site	Name	Age Oldest ^{14}C years	Age Youngest ^{14}C years	Latitude, Decimal	Longitude, Decimal
1153	Irvin Lake	13854	-32	47.135556	-93.643611
1151	Iola Bog	13522	117	44.5	-89.116944
1157	Jack Lake	13591	21	47.316667	-81.766667
1163	Jacobson Lake	12821	7058	46.416944	-92.716944
1255	Jewell Site	13854	969	42.26	-93.7
1447	Kellys Hollow	11417	-29	45.3	-90.35
1448	Kellners Lake	16809	-23	44.238056	-87.848056
1520	Kirchner Marsh	13658	228	44.77085	-93.12255
1524	Kitchner Lake	12951	-21	45.666667	-87.455
1548	Kotiranta Lake	18252	164	46.72	-92.62
1564	Kylen Lake	19064	9431	47.35	-91.8
1571	Lac Louis			47.2875	-79.116667
1580	Lake Sixteen	13640	2219	45.6	-84.316667
1588	Lake Carlson	14064	11	44.79985	-93.15975
1606	Lake QC	12895	0	46.828333	-80.698333
1607	Lake Six	10389	23	48.4	-81.316667
1633	Lily Lake (US:Minnesota)	17839	0	45.05	-92.825
1639	Little Bass Lake	12650	0	47.286	-93.600465
1649	Lake of the Clouds	11707	8521	48	-91.116667
1665	Lost Lake	11553	0	46.719435	-87.97207
1701	Maplehurst Lake	15388	30	43.225	-80.659722
1708	Martin Pond	12883	0	47.173975	-94.943965
1732	Medicine Lake	12734	10288	44.98419	-97.350125
1735	Lake Mendota	13314	0	43.1	-89.416667
1759	Mirror Pool	10630	10183	46.525833	-97.241389
1768	Moon Lake	13969	-35	46.85592	-98.15984
1770	Mordsger Lake	10520	22	51.383333	-94.25
1786	Myrtle Lake	12939	0	47.982605	-93.3853
1799	Nichols Brook Site	14932	9517	42.544722	-78.478889
1807	Nina Lake	11827	18	46.6	-81.5
1820	Nutt Lake	11101	-34	45.216667	-79.45
1824	Lake West Okoboji	17237	0	43.333333	-95.2
1829	Oliver Pond	12110	-24	48.422222	-89.323889

Table 2.1 continued

Site	Name	Age Oldest ^{14}C years	Age Youngest ^{14}C years	Latitude, Decimal	Longitude, Decimal
1862	Pass Lake	11417	0	48.56	-88.74
1834	Lake Ontario, Mississauga Basin	13854	6	43.556667	-78.15
1848	Panther Run Pond	16233	0	40.8	-77.416667
1857	Parkhill Creek	13075	-40	43.18	-81.75
1897	Pilot Mound Site	16048	400	42.16	-93.9
1963	Pond Mills Pond	9511	0	42.916667	-81.25
1966	Portage Lake	13652	12	47.081	-94.113
2011	Radtke Lake	13325	0	43.4	-88.1
2053	Reidel Lake	13439	-31	46.211944	-95.284167
2065	Rice Lake	11146	-30	48.00942	-101.53972
2068	R Lake	9579	0	54.305556	-84.558333
2287	Rose Swamp	12761	-28	44.18	-79.44
2288	Rosebud	14375	13661	43.229167	-100.848611
2289	Rose Lake	17315	75	41.916667	-77.925
2290	Rossburg Bog	14120	1953	46.583333	-93.6
2293	Rostock Mammoth Site	19158	11296	43.5	-81
2314	Rutz Lake	13709	-3	44.87083	-93.858975
2318	Ryerse Lake	10105	596	46.131944	-85.179167
2355	Seidel	15246	9442	44.45	-87.515556
2366	Seminary Site	11341	11257	46.925	-96.758333
2372	Sewell Lake	12750	0	49.84135	-99.5763
2382	Shouldice Lake	11306	9	45.15	-81.416667
2393	Sioux Pond	11712	3352	49.933333	-91.566667
2586	Spirit Lake	13637	-20	46.47	-86.958333
2607	Stone Lake Tamarack Swamp	12783	256	44.891667	-93.691667
2638	Quallen Lake [Terhell Pond]	12496	-8	47.19324	-95.786645
2640	Thompson Pond	11884	6	47.19482	-96.09332
2888	Upper Graven Lake	12939	12	46.184444	-95.306944
2890	Upper Mallot Lake	12515	0	47.308333	-84.258333
2903	Van Nostrand Lake	17475	0	44	-79.38
2956	Willow River Pond	8919	5563	46.324305	-92.78081
2960	Winter Gulf Site	15083	14641	42.561111	-78.933889

Table 2.1 continued

Site	Name	Age Oldest ^{14}C years	Age Youngest ^{14}C years	Latitude, Decimal	Longitude, Decimal
3032	Wolverine Lake	11745	100	46.429167	-85.661111
2961	Wintergreen Lake	15088	-20	42.4	-85.383333
3029	Wolf Creek	24679	10183	46.116667	-94.116667
3031	Wolsfeld Lake	13864	-25	45.005	-93.5727
3042	Wylde Lake	14533	-25	43.91	-80.4
3047	Yellow Dog Pond	10293	0	46.75	-87.95
3050	Zuehl Farm Site	15332	966	43.03	-93.87
3051	Found Lake	9999	0	45.55	-78.64
3055				0	0
3081	Disterhaft Farm Bog	16631	529	43.916944	-89.166944
3125	E Lake	13527	-18	50.69095	-99.65835
3452	Kellys Hollow	12757	-29	45.3	-90.35
3455	Kirchner Marsh	14093	10	44.77085	-93.12255
3468	Lake Ann	12576	722	45.425	-93.6875
3469	Lake Ann	15808	5589	45.425	-93.6875
3473	Lake Mary	12157	254	46.25	-89.9
3482	Lake of the Clouds	8801	152	48	-91.116667
3487	Medicine Lake	12861	0	44.98419	-97.350125
3488	Lake Mendota	16862	75	43.1	-89.416667
3542	Pickerel Lake	13043	0	45.501375	-97.27683
3558	Pogonia Bog Pond	13025	-24	45.03503	-93.6305
3583	Rosebud	14924	14835	43.229167	-100.848611
3620	Seidel	13124	32	44.45	-87.515556
3774	Spiritwood Lake	12515	-18	47.074695	-98.5866
3781	Stewart's Dark Lake	12685	516	45.3	-91.45
3784	Third Lake	11375	164	48.108333	-92.016667
3831	Vestaburg Bog	24170	0	43.416667	-84.883333
3837	Weber Lake	18446	10	47.471667	-91.66
3841	White Lily Lake	19337	8913	46.086111	-93.102778
7856	Roberts Creek CCLG-1A	14706	14706	42.986111	-91.500278
13029	Sharkey Lake	12082	65	44.5924	-93.4132
13032	Kimble Pond	12254	-48	44.21895	-93.84015
13051	West Olaf Lake	8633	-25	46.5986	-96.18675
13097	Glimmerglass Lake	11678	52	46.21517	-89.32082

Table 2.1 continued

Site	Name	Age Oldest ^{14}C years	Age Youngest ^{14}C years	Latitude, Decimal	Longitude, Decimal
14537	Kelly-Dudley Lake	7180	17	44.354435	-93.365935
14410	Tower Lake	8775	1697	46.542635	-86.037795
15136	Devils Lake, Creel Bay	14338	-36	48.0859	-98.92935
15138	Jones Lake	11212	-50	49.450245	-99.289145
15140	Mallard Pond	8267	-48	51.287795	-101.32475
15153	Wendel site	13351	9092	46.433115	-98.28941
15199	Soth Dansville Buried Peat	19041	1085	42.49185	-77.641
15203	Crawford Bog	10286	-29	43.466528	-79.949167
15281	Williams Lake	10787	-43	46.95391	-94.66923
15286	West Hawk Lake	23868	249	49.76341	-95.191725
15296	Byron-Bergen Swamp (Site 1)	19897	128	43.09791	-78.014515
15302	Emrick Lake	11113	-54	43.800155	-89.59428
15309	East Soldier Lake	9381	10	46.34668	-84.857625
15403	Deep Lake	8214	143	47.683805	-95.398395
15588	Devil's Bathtub	13194	1813	43.02469	-77.57376
15660	Buck Lake	8393	-34	46.520515	-86.35387
15682	Canyon Lake	11320	-10	46.833333	-87.921389
15740	Hemlock Lake	10717	-32	46.3073	-91.19829
15819	Porcupine Mountain	7969	-17	52.50635	-101.62995
15916	Kerr Lake	8621	865	46.24378	-89.2758
15919	Crooked Lake	10136	-12	46.24525	-89.29409
15922	Jay Lake	10360	36	46.23435	-89.28155
15925	Lake O' Pines	11704	-38	46.140435	-89.2553
15929	Hiscock Site	13006	177	43	-78

Next, the downloaded raw frequency data for the eight pollen types of interest for each of the 165 sites were averaged for the time slots i.e. 8,000-8,250 ^{14}C yrs. BP, 8,250-8,500 ^{14}C yrs. BP, 8,500- 8,750 ^{14}C yrs. BP, 8,750- 9,000 ^{14}C yrs. BP, 9,000-9,500 ^{14}C yrs. BP, 9,500-10,000 ^{14}C yrs. BP, 10,000-10,250 ^{14}C yrs. BP, 10,250- 10, 500 ^{14}C yrs. BP, 10,500-10,750 ^{14}C yrs. BP, 10,750-11,000 ^{14}C yrs. BP, 11,000-11,500 ^{14}C yrs. BP, 11,500-12,000 ^{14}C yrs. BP, 12,000-12,500 ^{14}C yrs.

BP, 12,500-13,000 ^{14}C yrs. BP, 13,000-13,500 ^{14}C yrs. BP, 13,500-14,000 ^{14}C yrs. BP, 14,000-14,500 ^{14}C yrs. BP, 14,500-15,000 ^{14}C yrs. BP, 15,000-15,500 ^{14}C yrs. BP and 15,500-16,000 ^{14}C yrs. BP . During averaging, if there was a transition between pollen core dates that did not fit clearly into a specific time slot, all efforts were made to correlate the date with the closest 250 or 500 ^{14}C year For example, if the species was identified as disappearing from a pollen core at 10,499 ^{14}C yrs. BP and 10,250 ^{14}C yrs. BP then it fell into the block of 10,250-10,500 ^{14}C yrs. BP, but if the value was exact at 10,500 then it fell into 10,500-10,750 ^{14}C yrs. BP block. Also, the time ranges was divided based upon the occurrence of events like Younger Dryas, advancement of Lake Agassiz and Intra-Allerød along with 8.2 ka (8,000-7,000 ^{14}C yrs. BP). Most specifically the dates that fall within the range of 8,000-9,000 ^{14}C yrs. BP and 10,000-11,000 ^{14}C yrs. BP is divided into 250 year interval while the other dates were divided into 500 year intervals. As 11,000- 10,000 ^{14}C yrs. BP represents the time when Younger Dryas is assumed to occur, there was assumption of some inference upon the vegetation as well. For 8,000 ^{14}C yrs. BP is some time before the 8.2 ka event (ranges from 8,000-7,000 ^{14}C yrs. BP), hence it was decided to use the interval of 250 yrs for 8,000-9,000 ^{14}C yrs BP and 10,000-11,000 ^{14}C yrs. BP. After deciding upon the time interval ranges, the next step was averaging the raw frequency count data that fall within the range for each species and each site. Then a separate spreadsheet was prepared for each of the taxa of interest either the idealized caribou habitat (*Betula spp*., Cyperaceae, Ericaceae, *Picea spp*., *Salix spp*., and *Sphagnum spp*.) or post-caribou habitat indicators (*Pinus spp*. and *Quercus spp*.). Occasionally Ericaceae and *Sphagnum* were absent from the samples data. Then using ArcMap and the percentage value along with the location of each site for each of eight taxa, a time series proportional symbol map was produced for each taxon.

Then, Ward's linkage using correlation matrix with untransformed percentage value and Euclidean distance for cluster analysis was used so as to know which of the species occur together for all the time intervals using MINITAB 15. Then the cluster was correlated with the trend outlined through each species time-series maps.

The last component of analysis was to group the 165, sites into geographically cohesive areas. After cluster analysis, there was a need to know where the prime caribou habitat was located during different time intervals and how it moved in time. Therefore, the percentage data for the idealized caribou habitat species i.e. (*Betula spp*., Cyperaceae, Ericaceae, *Picea spp*., *Salix spp*., and *Sphagnum spp*.) was used. Square root of the percentage value for each of the species instead of using the percentage value to de-emphasize the importance of *Picea* was used which tends to dominate pollen spectra at the time and totaled. Then the totaled value was interpolated using Inverse Distance Weighing method in ArcGIS (IDW) where the interpolated values were weighted using the total of square root of percentage of each of the species. Then a time series of interpolated maps was produced where the values were color coded using highest to lowest percentage values. The colors with highest percentage values from 20-25% represent the locations of prime caribou habitat while the color that represents 15-20% of the species was termed as favorable caribou habitat.

There are some factors that needs to be considered in this study. The study relies upon a series of radiocarbon dates, a lot of which are interpolated dates rather than dates made directly on individual samples from the deeper layers, and that might result in some erroneous values. The pollen sites were superimposed on the ice-sheet maps produced by Dyke and Robertson (2003), some mismatches can be observed where the pollen sample locales on top of the ice-sheet, which is also due to the radiocarbon dates being used and that being the interpolated values rather than real ones. Also, Dyke and Robertson (2003) might have produced the ice-sheet shapefiles with some error themselves. Therefore, some errors might be because the ice-sheet data was not exact what was there during the same time. Also, I averaged the values of each species while I converted it into the range of time slices where there might be some errors associated during the conversion.

Chapter III: RESULTS

Out of 255 sites that were downloaded from the Neotoma database, only 165 sites in total were used for study because of various reasons. Since the study was specific to time, i.e., from 15,000^{14}C yrs. BP to 8,000 ^{14}C yrs. BP, only the sites that fall within that range were used in the research. Also, some plots were not within the study area, i.e., beyond the Great Lakes region. Some sites were discovered to contain calibrated years for age, those were not used in this analysis. For each of the maps, pollen percentages vary from the level that indicate low abundance of that taxon up to levels that reveal the location of major population centers. Actual percentage for the contoured lines differ from one plant group to another because the amount of pollen produced and its dispersal distance varies widely from taxon to taxon (Jacobson et. al, 1987). Some smoothing of the plotted data inevitably is found in the map where the species as a total are interpolated and I recognize that maps are not accurate in every detail. Furthermore, pollen studies have not differentiated between the several component species for many of the families and genera mapped. It is an assumption that the maps fail to reveal some important geographical patterns within the taxa shown. The goal, however, is to show how the population centers for important plants shifted position during the most recent deglaciation of the Great Lakes region of North America, and this was accomplished in this research.

Time-series map of each taxon

As an example of how individual plant taxa changed in location and abundance during deglaciation on figure 3.1-3.10 presents time series map of sedges *(Cyperaceae),* Spruce

(Picea), Birch *(Betula),* Fir *(Abies),* peat moss *(Sphagnum),* willow *(Salix),* heath *(Ericaceae),* pine *(Pinus)* and oak *(Quercus).* Ice positions follow the mapped summaries from Dyke and Robertson (2003).

Spruce.

During full glacial conditions across the Great Lakes region, spruce was abundant south of the Laurentide ice sheet. The population center for *Picea* is concentrated in three regions: Minnesota, between Lake Huron and Lake Ontario, and in north Michigan. The clustering starts from 13,000 ^{14}C yrs. BP, which at that point in time is to the south of the ice margin. Spruce shows one of the highest proportions among all studied species. The population center starts declining after 10,000 ^{14}C yrs. BP, with relatively high abundances restricted to narrow band immediately south of the ice. As the population declined since 10,000 ^{14}C yrs. BP, it also starts to scatter away from the population center. Also, during the same time, the population didn't get restricted to the edges of the ice sheets, it started to move away from the edge of the ice sheet. This is the lowest point for *Picea* from 15,000 ^{14}C yrs. BP onward. The modern distribution of spruce in the boreal forest had emerged by 4,000 ^{14}C yrs. BP, as the last vestiges of the ice sheet disappeared (Chapin and Shaver, 1985).

Figure 3.1

Pollen abundance of *Picea* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

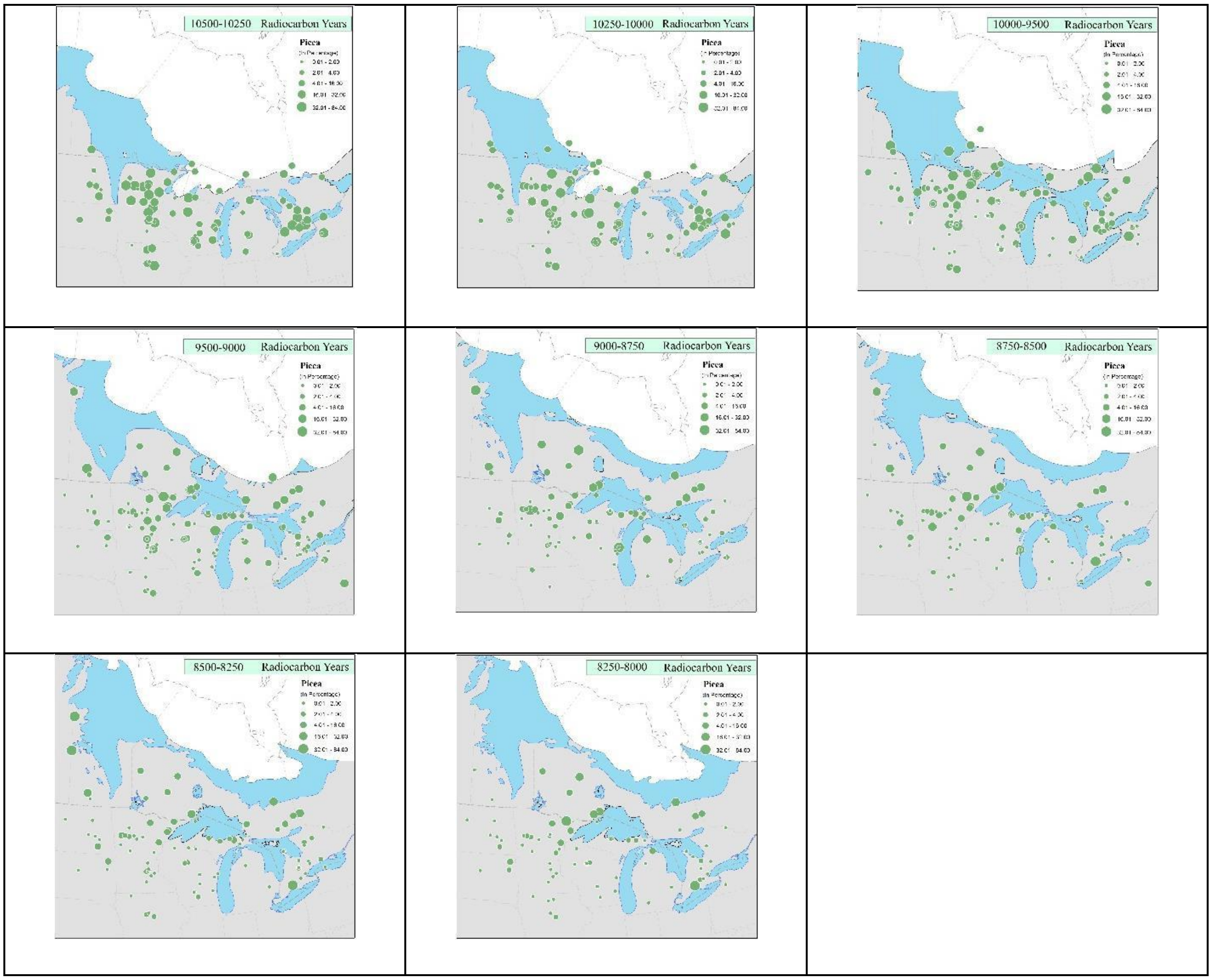


Figure 3.1 continued

Sedges (*Cyperaceae*).

Sedges today are abundant in the prairie and tundra regions across the broad region of eastern North America and south of the Laurentide ice-sheet (Wright, 1968). The geographic extent of this family of grass-like plants remained broad until sometime between 12,000 ^{14}C yrs. BP and 9,000 ^{14}C yrs. BP, when the widespread populations concentrated in three centers, one in Minnesota, second in northern Michigan, and the last one between Lake Huron and Lake Ontario, but in greater proportion than *Betula* and *Abies* populations there at that time. This was a broad-scale distribution in the Great Lakes region where prairie grows today. There percentage value also remains higher in comparison to other species. The population center goes on increasing until 10,500 ^{14}C yrs. BP and then pollen center starts to scatter to other parts of the study area. Like *Picea*, as they start to scatter from the population center, their percentage value goes on decreasing until 8,000 ^{14}C yrs. BP. Looking through the pollen diagrams of Kirchner Marsh (Southeastern Minnesota), Wolf Creek (Central Minnesota) and Lake of the Clouds (North eastern Minnesota), the sedge population values do not decrease as much as the *Picea* population does after 10,000 ^{14}C yrs. BP. Also Wright (1968) indicated that this taxon is consistent with expansion of prairie in Indiana and western Ohio from 8,000 ^{14}C yrs. BP onward.

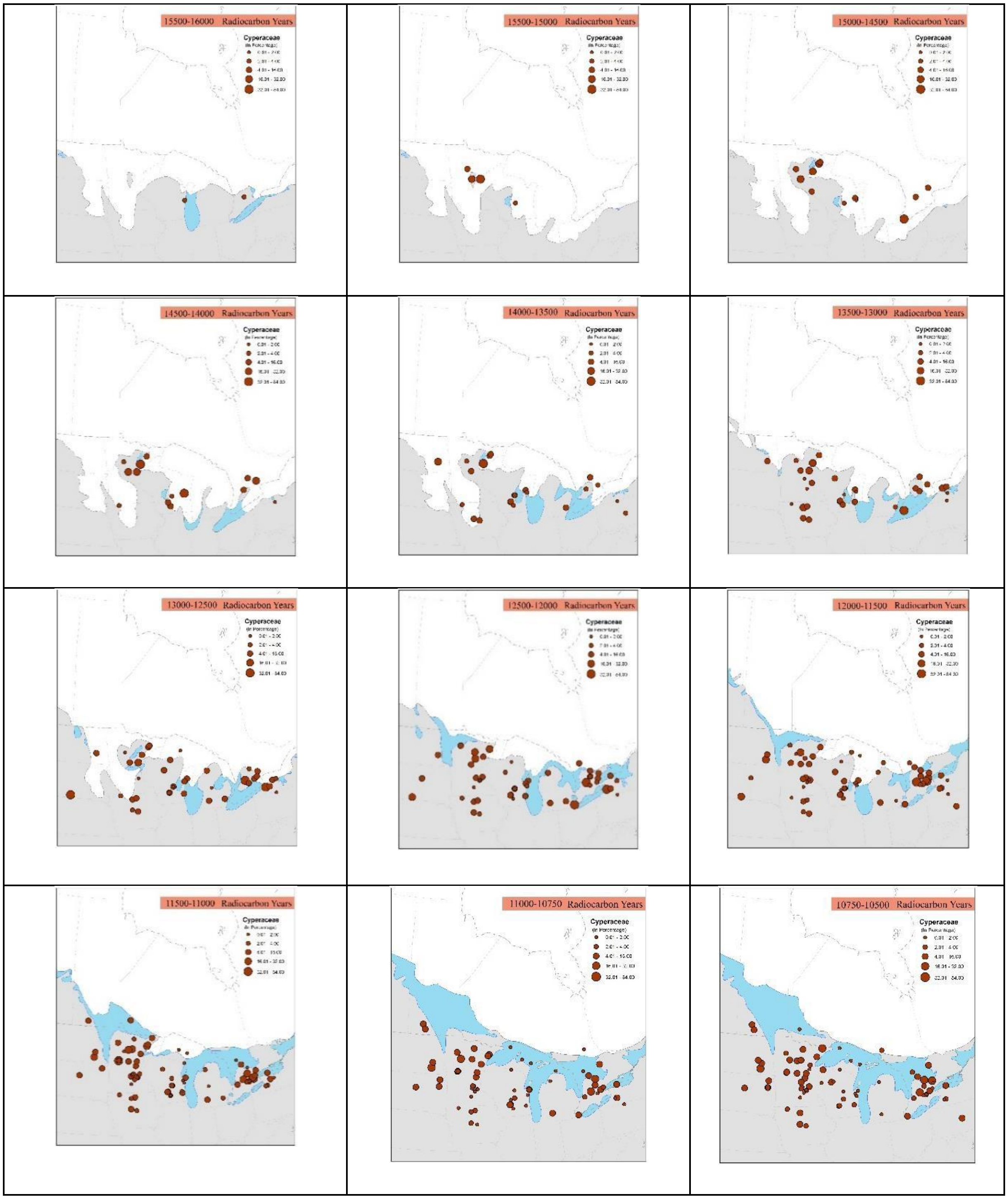


Figure 3.2
Pollen abundance of *Cyperaceae* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

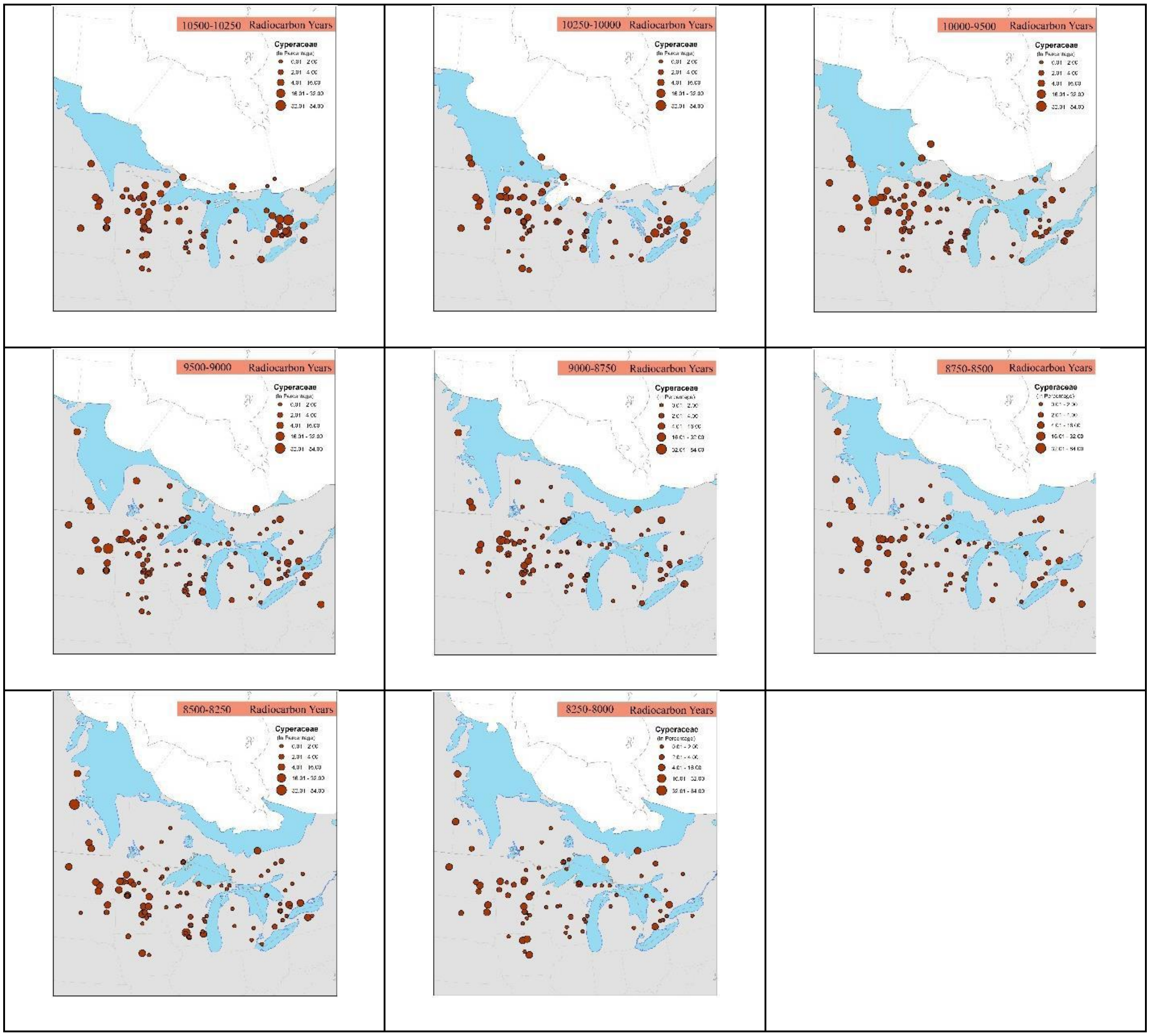


Figure 3.2 continued

Fir (*Abies*).

Today fir trees are an important compoment in coniferous forest of the Great Lakes reigon, but at 16,000 ^{14}C yrs. BP these were rare south of the ice sheet and remained so until 12,000 ^{14}C yrs. BP (Donna and Wright, 1979). Only around 12,000 ^{14}C yrs. BP did fir trees emerge in significant abundances across most of the area south of the ice sheet. As the ice sheet became restricted to smaller regions of the western Canada, fir populations increased rapidly in the Great Lakes region. Later, as Jacobson et al. (1987) states, we can see that even in the maps i.e. after 9,000 ^{14}C yrs. BP. most abundant populations were not in the same region. Compared to other species, their percentage values do not vary greatly until 12,000 ^{14}C yrs. BP and later until 8,000 ^{14}C yrs. BP it increases to the range of 16-32%. Also, unlike *Picea*, it doesn’t greatly decrease in value during the early-Holocene.

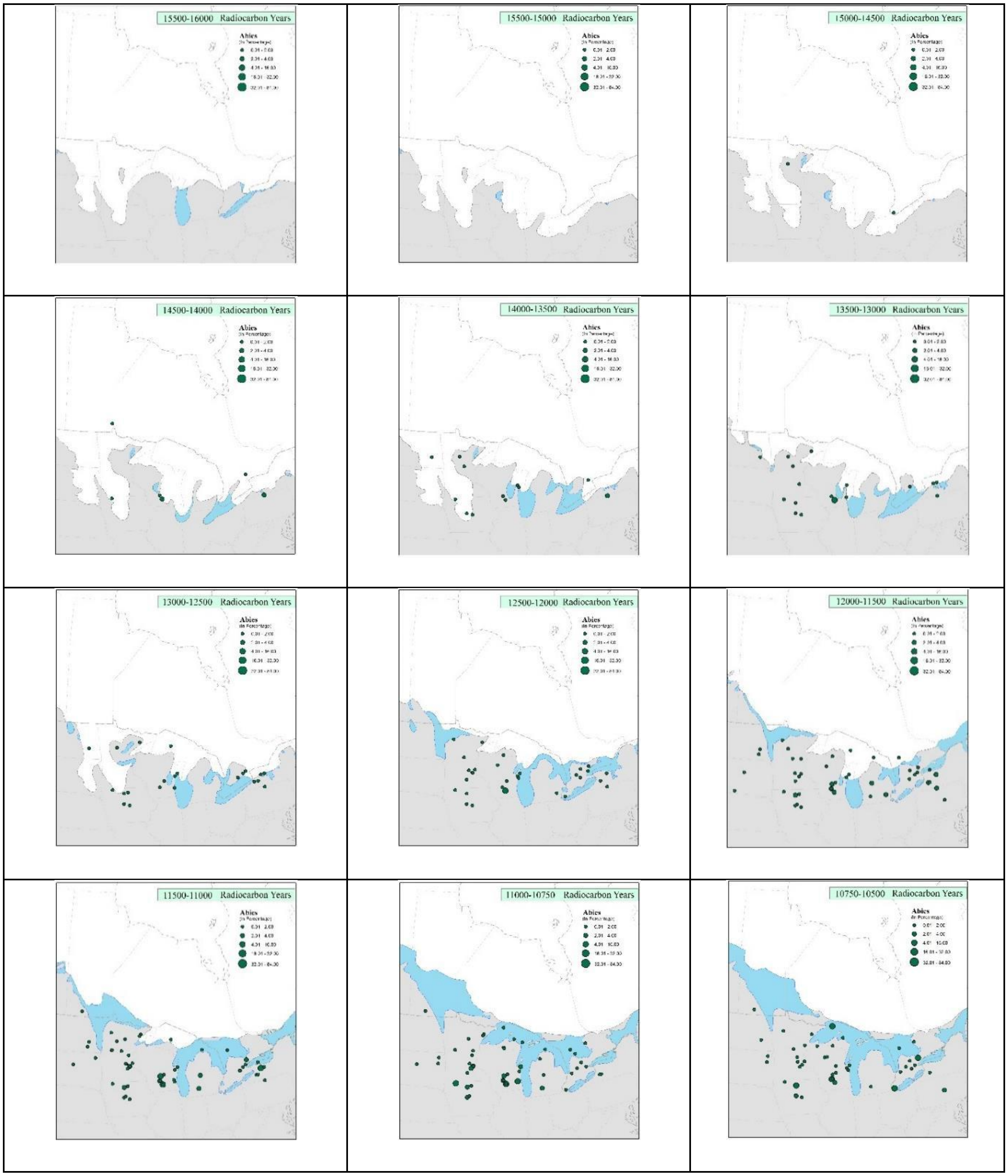


Figure 3.3
Pollen abundance of *Abies* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

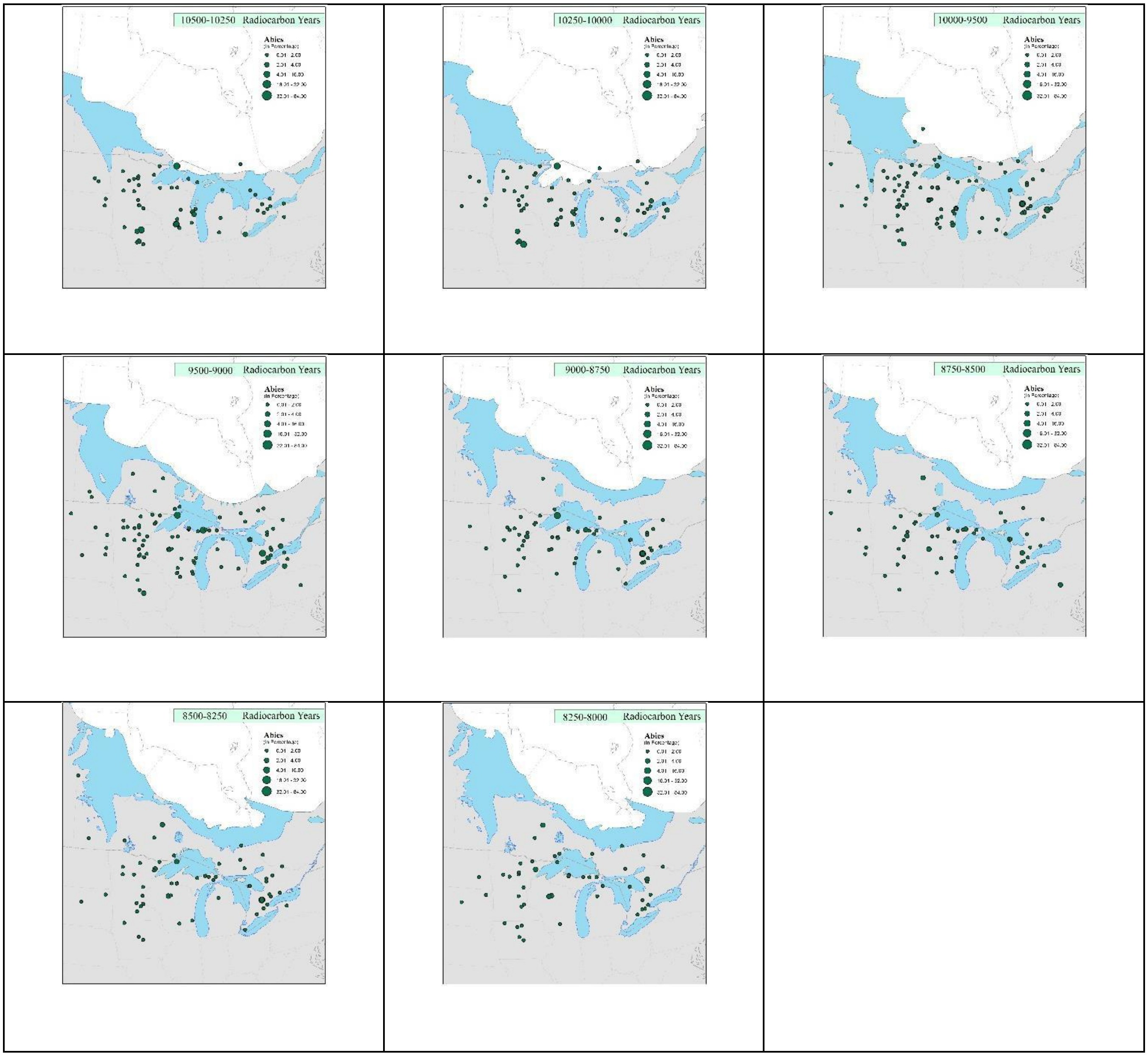


Figure 3.3 continued

Birch (Betula).

Birch trees are an important component in mixed forests of the Great Lakes region but at 16, 000 ^{14}C yrs. BP were in minimal amount towards the south of Laurentide ice-sheet. They grew in abundance after 13,000 ^{14}C yrs. BP across the south of the ice-sheet. It is known to be one of the first successional species as evidenced by its presence towards the ice-edge more than any other species (Moos & Cumming, 2011). In comparison to *Abies*, their percentage values are higher and their maximum range is up to 82%. Also, they are spread widely across the region unlike *Picea*, although it does get clustered around the same region and within the same date range. But their percentage values in total starts to decline from 9,000^{14}C yrs. BP onward, but in proportion slightly higher than *Picea.*

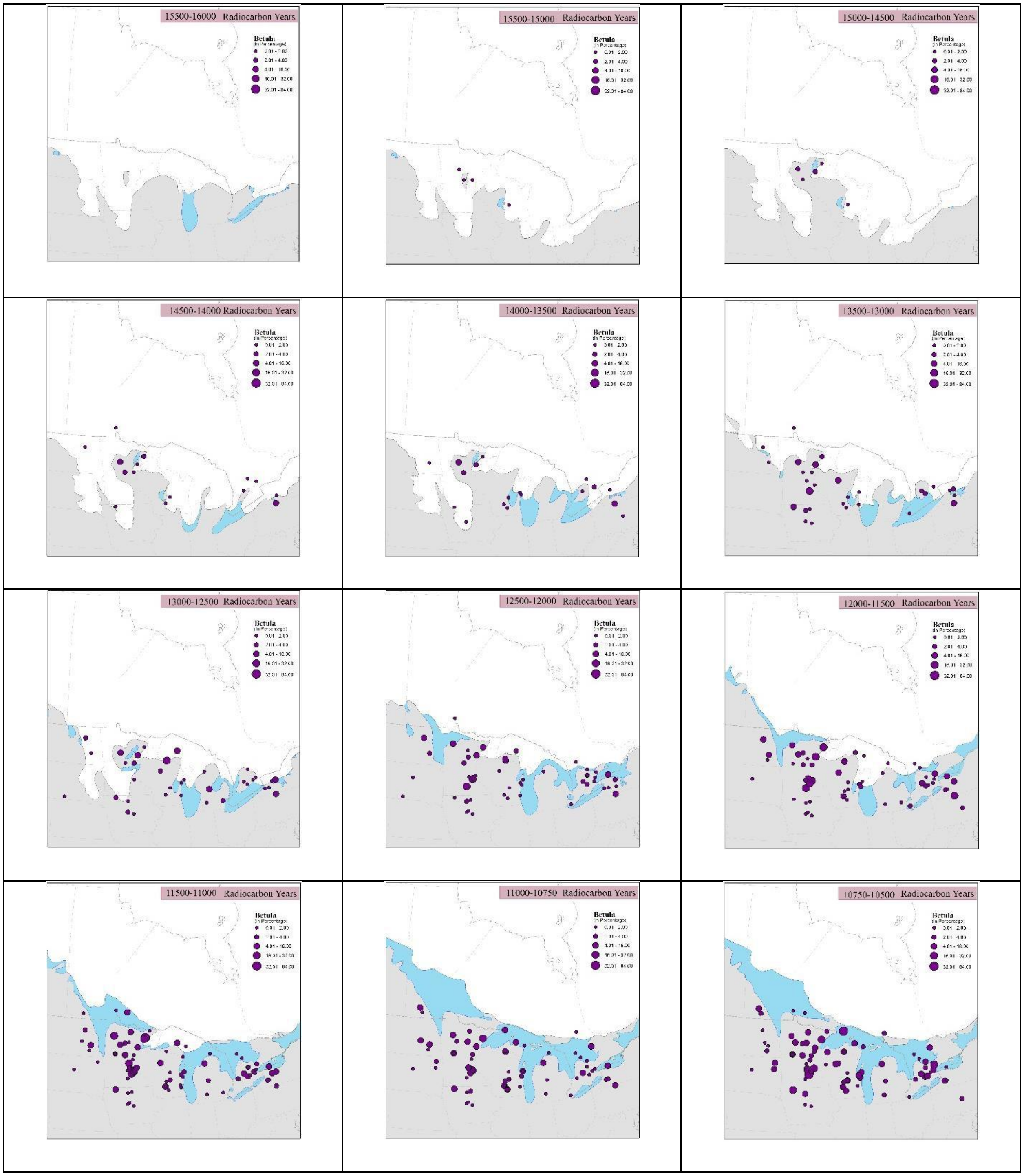


Figure 3.4
Pollen abundance of *Betula* displayed in precentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

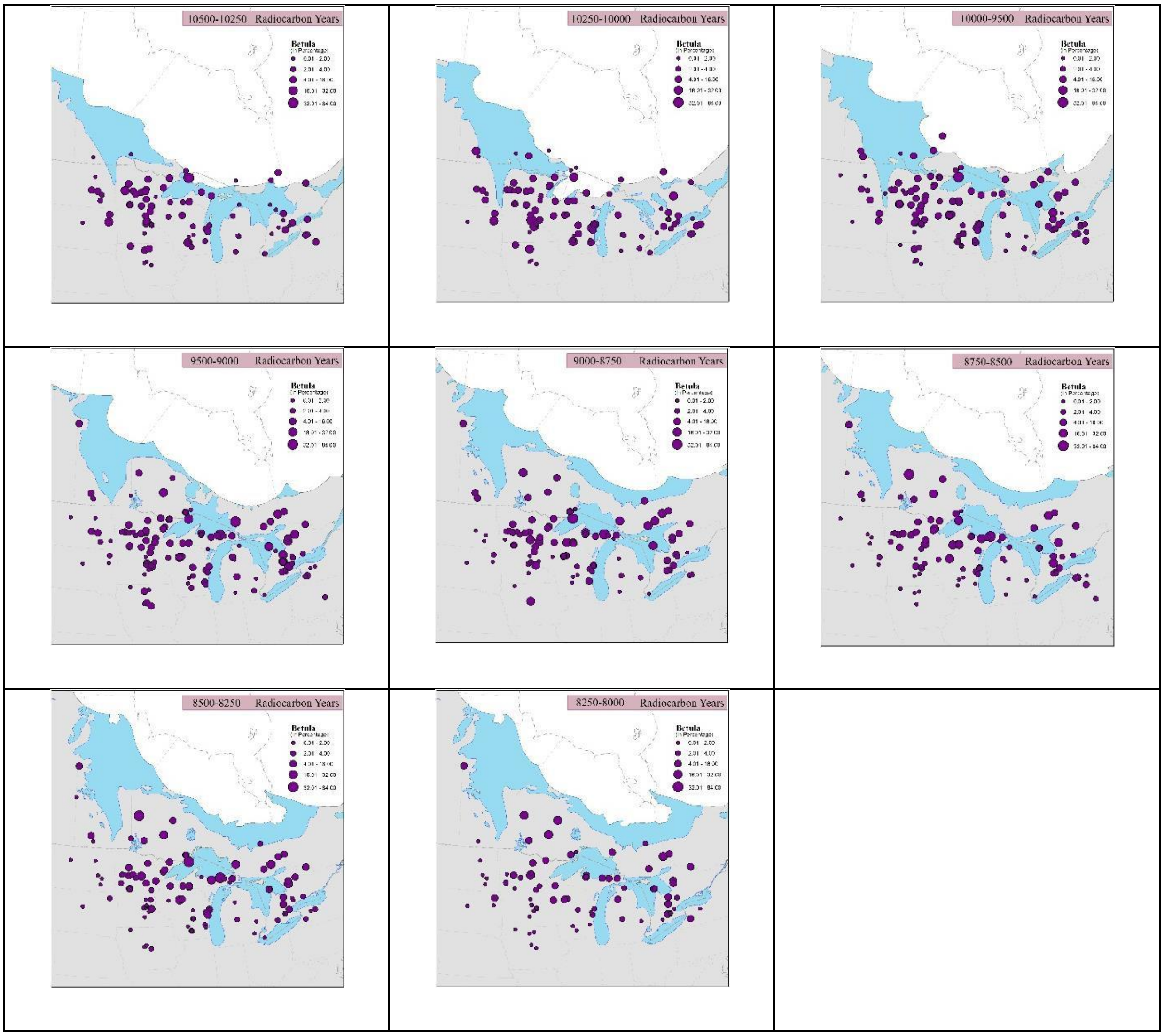


Figure 3.4 continued

Heath (Ericaceae).

Presently Ericaceae pollen is ubiquitous in all of North America except the desert (Williams et. al., 2004). These plants are well known for their propensity to grow in acidic soils (APG III, 2009). Also, Ericaceae is important because it forms the winter forage for Caribou. On Figures 3.5, it can be seen that during 12,000-11,000 ^{14}C yrs. BP, this taxon was mostly located in two regions within my study area, i.e. western Minnesota and between Lake Huron and Lake Ontario. Then from 11,000-10,000 ^{14}C yrs. BP it moves more north towards the north of Lake Huron and from 9,000 ^{14}C yrs. BP it gets restricted to Minnesota and Lake Huron. Although their percentage value is quite low compared to other species, Ericaceae is a significant winter forage for caribou. Hence, it supports the strong presence of caribou. This family is also a major indicator of boreal bogs, where a lot of growing shrubs belong to this family (APG III, 2009)

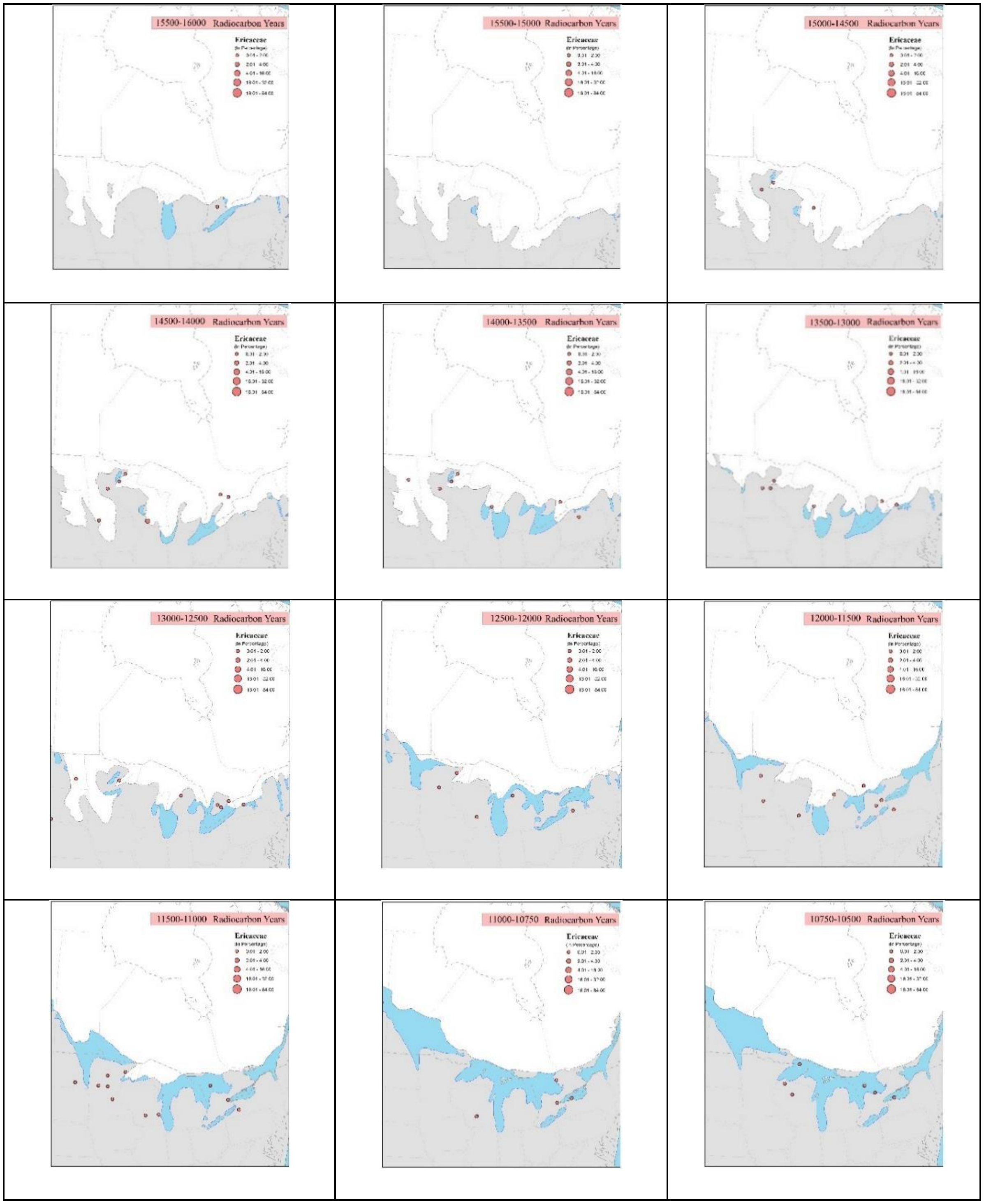


Figure 3.5
Pollen abundance of Ericaceae displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

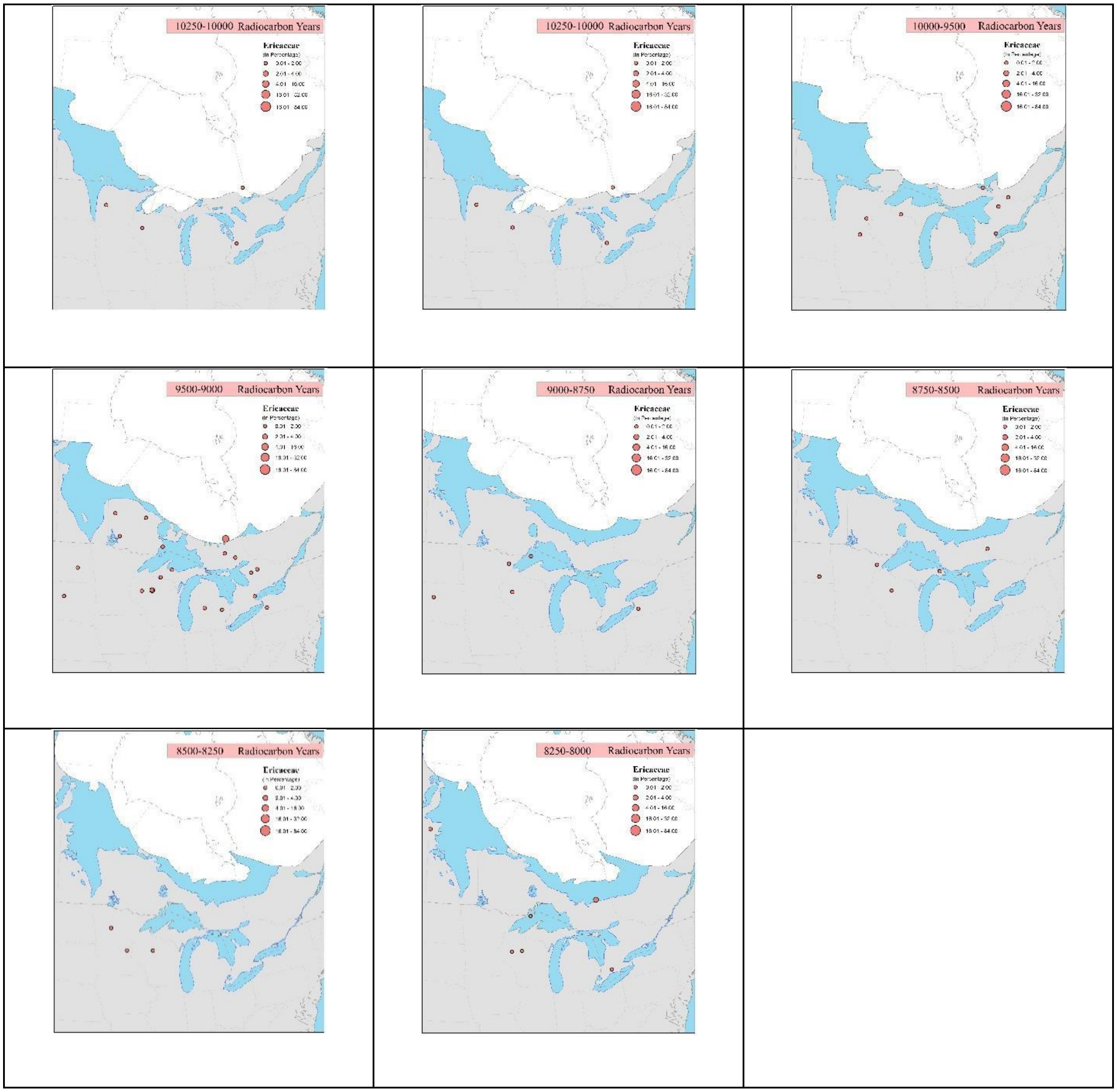


Figure 3.5 continued

Pine *(Pinus).*

According to Jacobson et al. (1987), between 16,000 ^{14}C yrs. BP to 10,000 ^{14}C yrs. BP, pines from their north-south trending population ceased to exist and the center of abundance was oriented in east-west band south of the wasting ice. This expansion subsequently expanded to form the northern-pine forests today. Through the maps in figure 3.6, it can be seen that clustering starts from 13,500 ^{14}C yrs. BP in Minnesota, between Lake Huron and Lake Ontario and Northern Michigan. As from, 10,000 ^{14}C yrs. BP, as the population of *Picea* starts to decrease, *Pinus* remains consistent in proportion. Also, compared to any other species, *Pinus* is abundant in terms of distribution as well as percentage values.

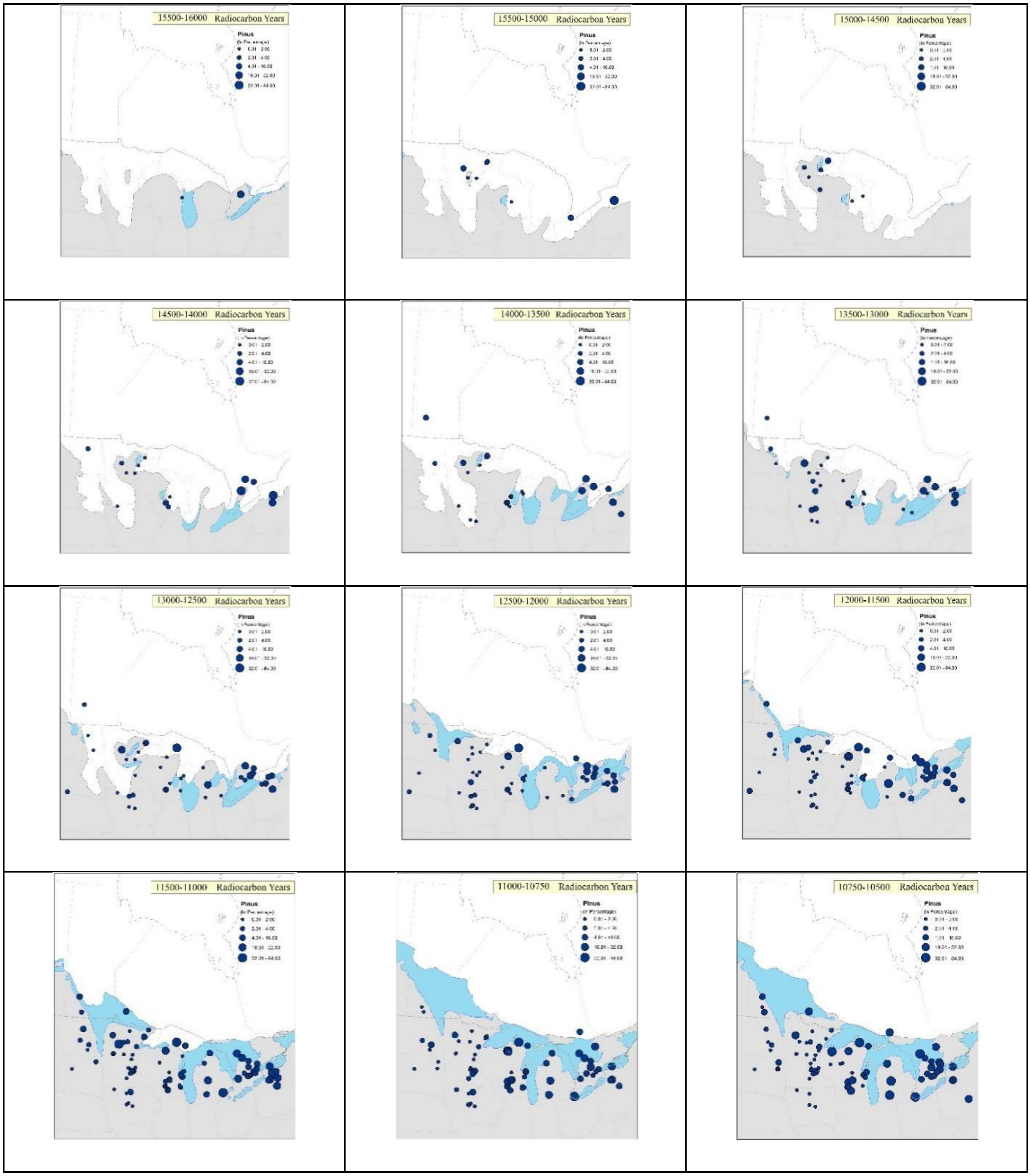


Figure 3.6
Pollen abundance of *Pinus* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

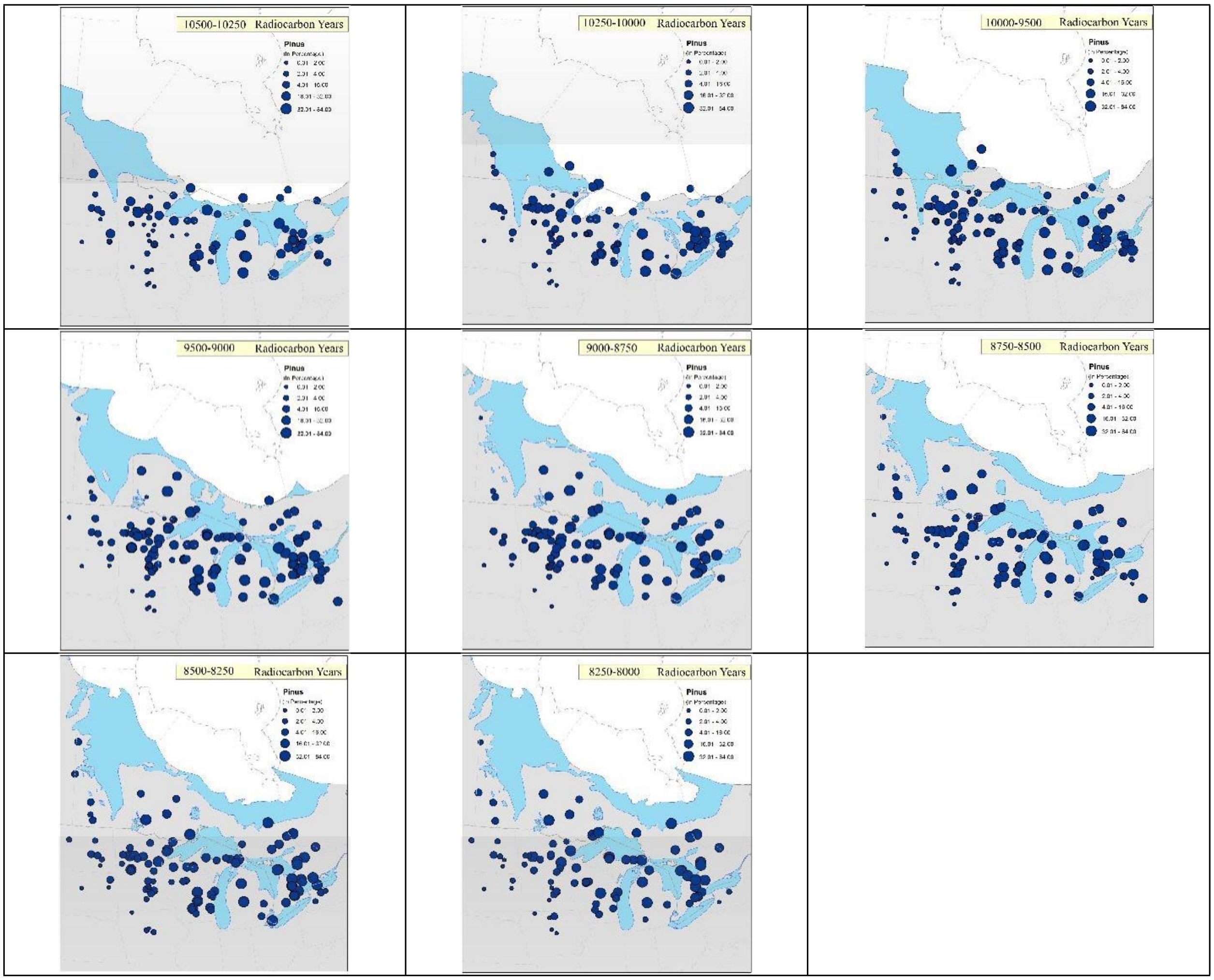


Figure 3.6 continued

Oak *(Quercus).*

Oaks are an important component of hardwood forest and certain species are particularly known to grow in associations with Ericaceae(APG III, 2009). Since 16,000 ^{14}C yrs. BP it has undergone dramatic changes in abundance and distribution, when they were restricted to the areas in South from the Atlantic coast across the region north of Gulf of Mexico (Jacobson et al., 1987). After, 10,000 ^{14}C yrs. BP, the center of distribution moved towards the receding icesheet. During the same time, *Picea* population start to decline, *Quercus* starts to increase. This pattern of distribution of abundance continues upto 8,000 ^{14}C yrs. BP.

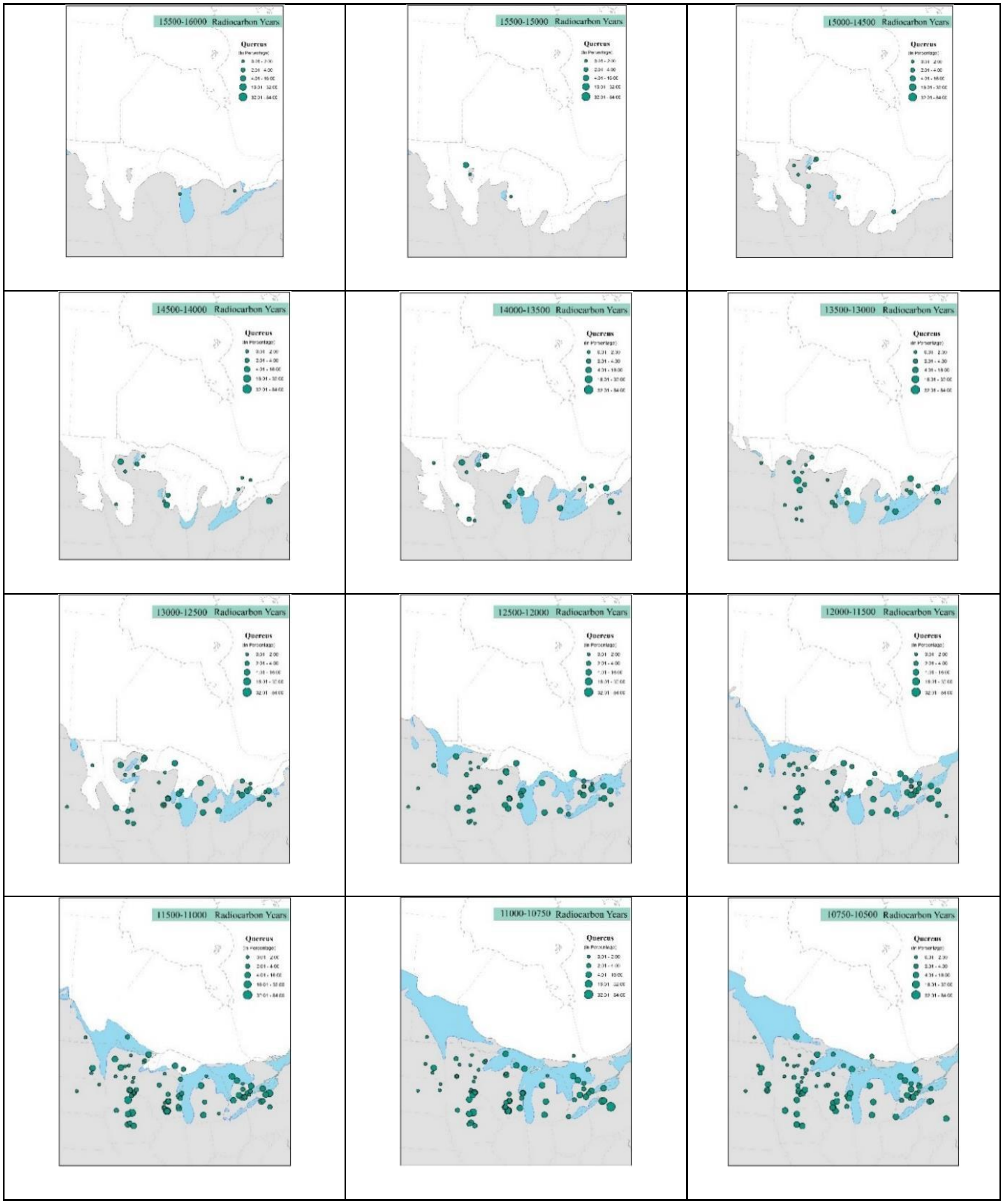


Figure 3.7
Pollen abundance of *Quercus* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

Figure 3.7 continued

Willow *(Salix).*

Presently it is found throughout the eastern United States, adjacent parts of Canada, and Mexico. Although, it does maintain similar population clustering regions and scattering from 10,000 ^{14}C yrs. BP on, one of the peculiar characteristic that is seen in maps is its absence from 12,500-12,000 ^{14}C yrs. BP which is during the Bølling-Allerød interstadial (Yu and Ulrich, 2001). This is the time which represents the very quick switch to warmer climates. It maintains its percentage range not beyond 32%.

Figure 3.8
Pollen abundance of *Salix* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

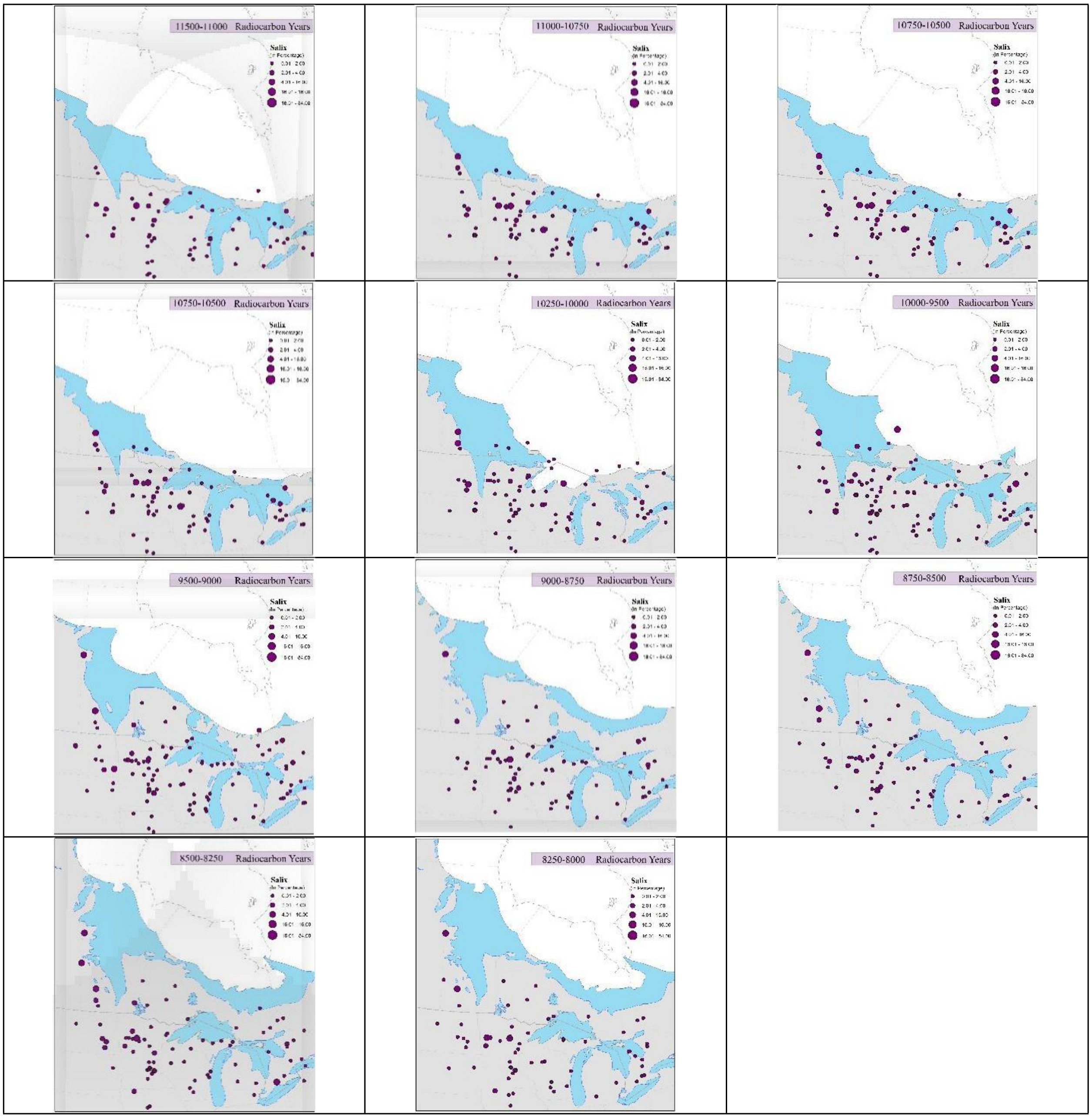


Figure 3.8 continued

Sphagnum.

Today spaghnum mosses occur mainly in the Northern Hemisphere in peat bogs, coniferous forests and moist tundra (Vitt and Slack, 1984). The geographic distribution of *Sphagnum* spores is similar to pollen from many other species. They start clustering around 12,000 ^{14}C yrs. BP along the same three geographical regions i.e Minnesota, between Lake Huron and Lake Ontario and and north Michigan. Then it starts to declutter after 9,000 ^{14}C yrs. BP. Also their percentage doesn't exceed 32%.

Figure 3.9
Pollen abundance of *Sphagnum* displayed in percentage range values of 0-2%, 2-4%, 4-16%, 16-32% and 32-84%

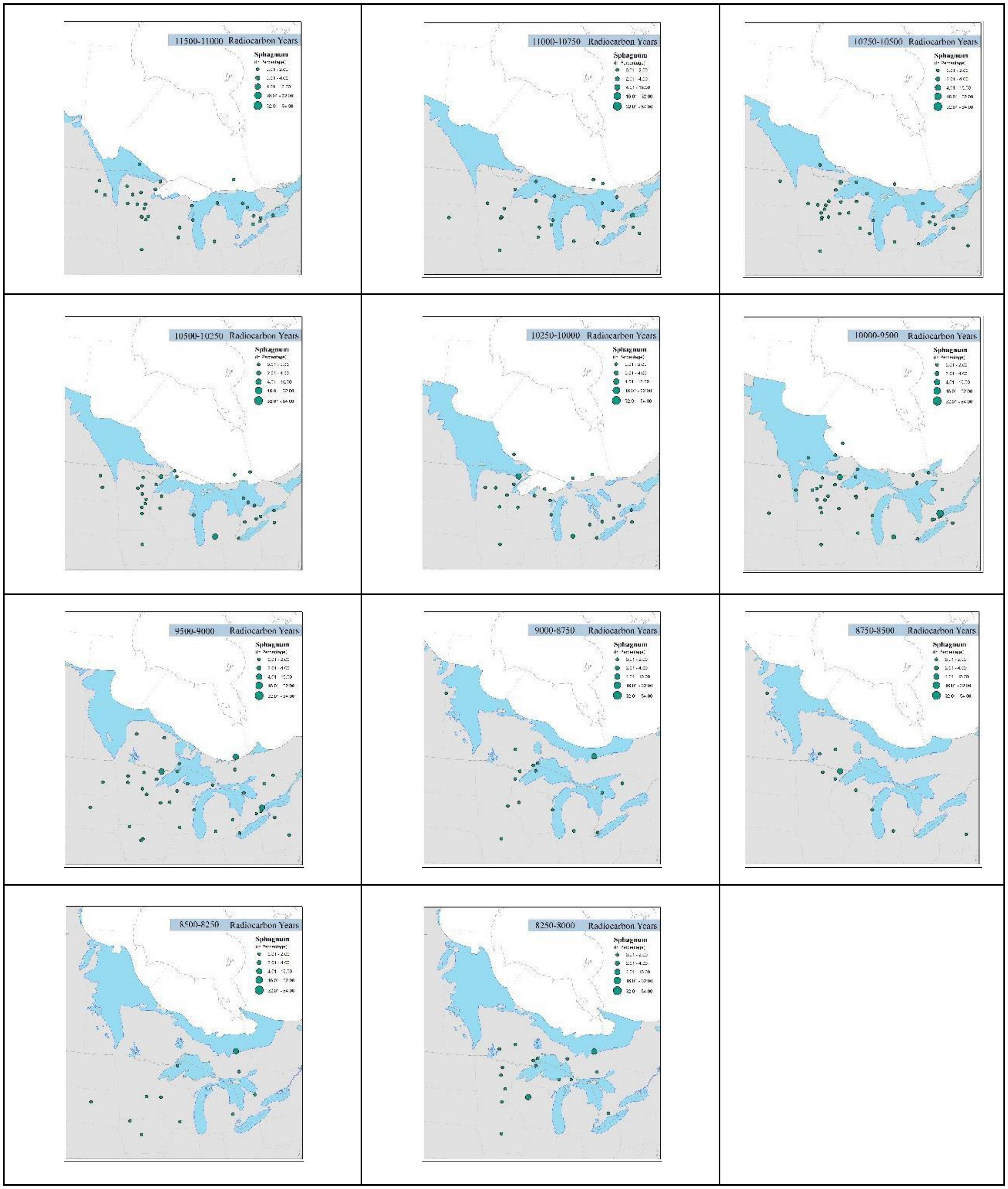


Figure 3.9 continued

Cluster analysis by variable at different time periods

Ward method of linkage and correlation coefficient for distance measure was used for the cluster analysis in MINITAB 15. In these figures we can see three distinct clusters: *Picea-Salix-Cyperaceae*, *Sphagnum*-Ericaceae and *Abies-Betula* represent the standard pattern. These clusters represent the modern vegetation communities in the BWCAW because of which it represents a significant role in the study. With A total of 20 time slices is used for cluster analysis that excluded *Pinus* and *Quercus* as these species were counter-represented the species that favor the habitat of caribou.

In 6 out of 20 the three clusters are very distinct: *Picea-Salix-Cyperaceae*, *Sphagnum*-Ericaceae and *Abies-Betula* appear together. The specific time slices with this pattern are: 8,250-8,500 ^{14}C yrs. BP., 10,000-10,250 ^{14}C yrs. BP, 10,500-10,750 ^{14}C yrs. BP and 10,750-11,000 ^{14}C yrs. BP. In two time slices during 10,250-10,500 ^{14}C yrs. BP *Salix* was more removed from *Picea* and *Cyperaceae*, but otherwise the pattern looked very similar. In other time-slices, slightly different clusters emerge. Also, cluster *Picea-Salix-Cyperaceae* is present in nine slices starting from 16,000 until 12,000 ^{14}C yrs. BP except for the 14,000-14,500 ^{14}C yrs BP and 14,500-15,000 ^{14}C yrs. BP intervals, when *Betula* is mixed in. *Picea-Salix-Cyperaceae* cluster seems to be very robust over time. Cluster *Sphagnum*-Ericaceae is present in 14 time slices and in couple additional ones it is also more or less distinct. But there is no Ericaceae recorded in time slice of 15,000-15,500 ^{14}C yrs. BP. Cluster *Abies-Betula* is present in 13 slices. *Abies* is not found in any samples at 15,500-16,000 ^{14}C yrs. BP. This cluster seems to be more common since 12,000 ^{14}C yrs. BP.

Hence, the three clusters *Picea-Salix-Cyperaceae*, *Sphagnum*-Ericaceae and *Abies-Betula* represent a standard pattern in the overall cluster analysis. This arrangement starts from 12,000 ^{14}C yrs. BP and continues until 9,000 ^{14}C yrs. BP. This corresponds to three common types of upland vegetation which Heinselmann (1999) noted for present-day BWCAW ecosystem: Spruce-willow-cotton grass (which is from sedge family) bog, peat bog with heath and fir-birch forest. These are the modern type of vegetation communities common for example in the Boundary-Waters Canoe Area Wilderness (BWCAW) and Quetico Provincial Park in Ontario.

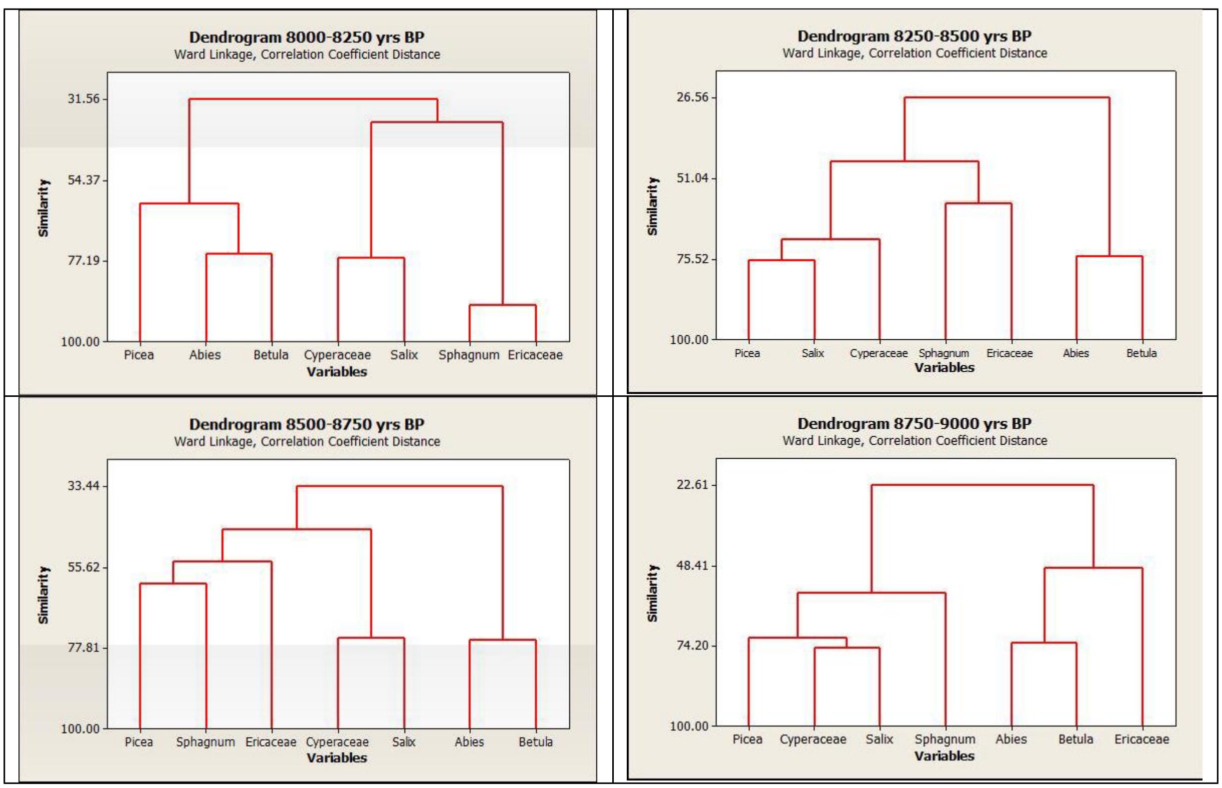


Figure 3.10
Species cluster diagram from 9,000 ^{14}C yrs. BP to 8,000 ^{14}C yrs. BP

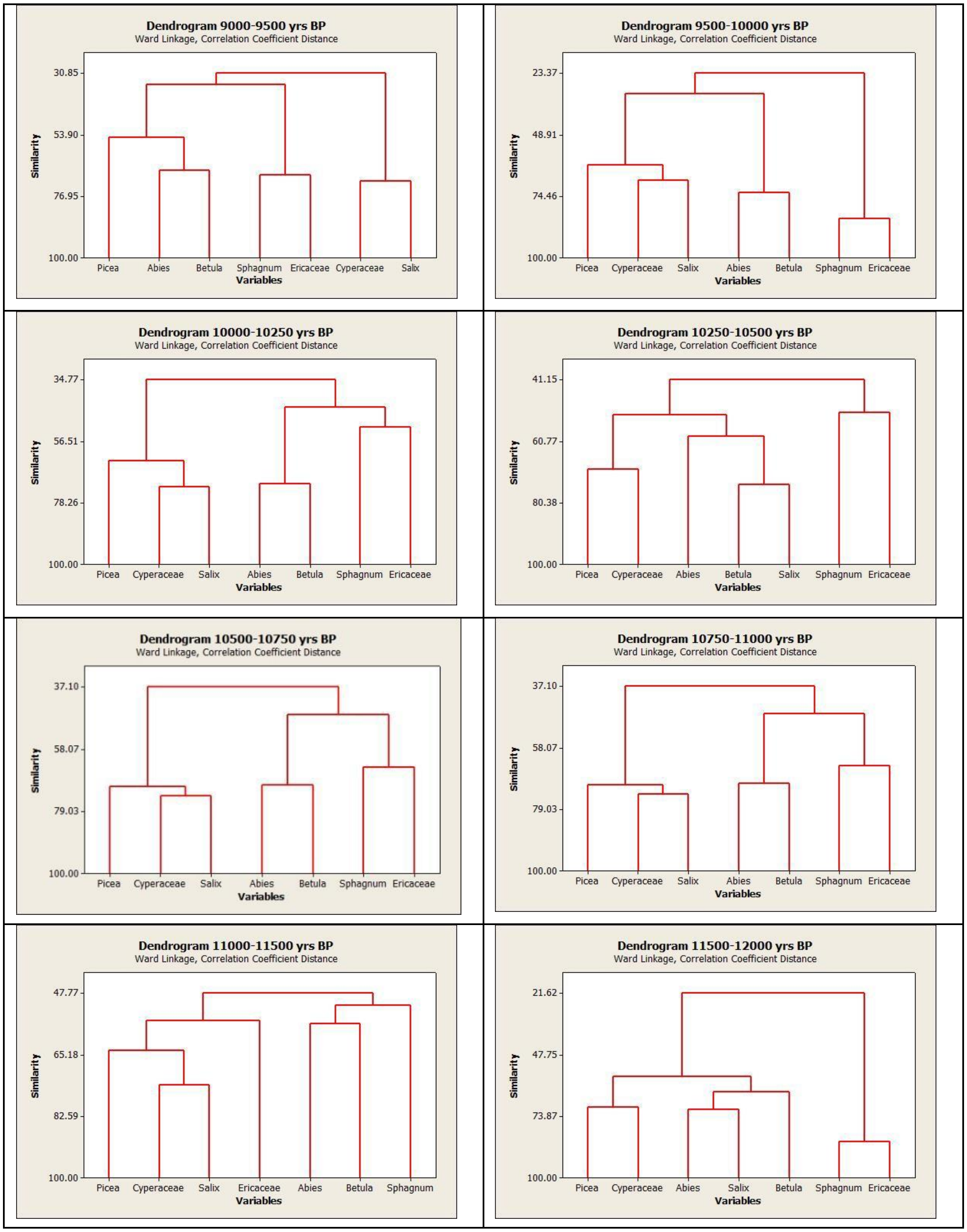


Figure 3.10 continued

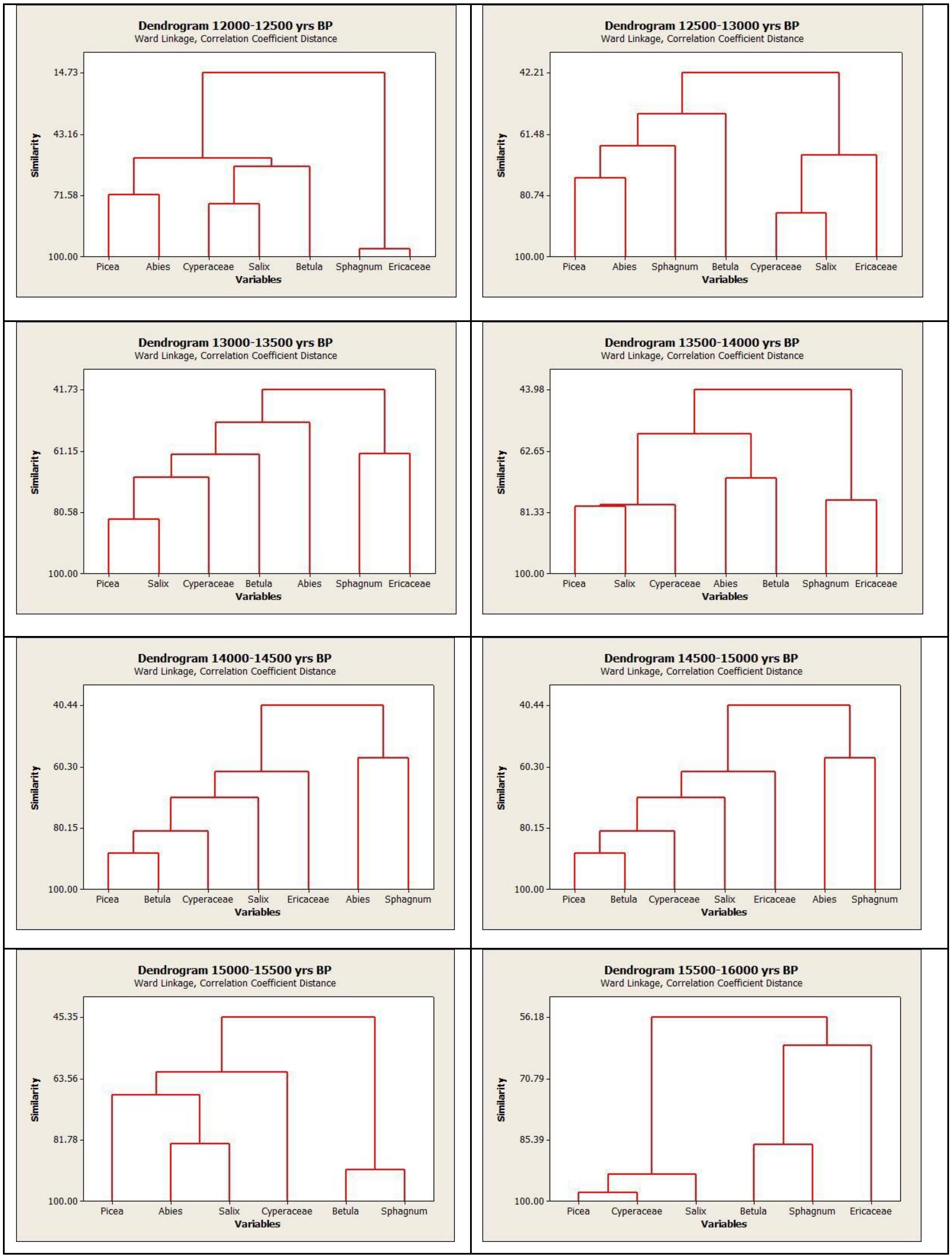


Figure 3.10 continued

Analysis using Interpolation

As there can be definite patterns identified by cluster analysis, it was evident to know where these patterns persisted in terms of location at different times. When all the target caribou species are added together, a “prime habitat” can be delineated. Here the number of sites for each time slice is different based on the presence and absence of species which is shown on Table 3. For example, the highest cumulative percentage values from 20-25% is the region defined prime habitat of caribou, while 15-20% represents favorable, but less optimal habitat for caribou. Early in deglaciation, the prime habitat gets restricted to ice-sheet margins, but starting around 12,500 ^{14}C yrs. BP, it gets restricted to three regions: Minnesota, areas between Lake Huron and Lake Ontario, and northern Michigan. The prime caribou habitat remains there until 10,000 ^{14}C yrs. BP, when there is no favorable or prime caribou habitat. After 10,500 ^{14}C yrs. BP, prime caribou habitat moves along the ice-edge and more towards the north until 8,000 ^{14}C yrs. BP.

Table 3.1
No of sites used in interpolation for each time slices

Time Slices	No of pollen sites used
8000-8250	96
8250-8500	116
8500-8750	107
8750-9000	104
9000-9500	138
9500-10000	127
10000-10250	102
10250-10500	91
10500-10750	86
10750-11000	100
11000-11500	89
11500-12000	69
12000-12500	56
12500-13000	42
13000-13500	36
13500-14000	24
14000-14500	17
14500-15000	14
15000-15500	12
15500-16000	5

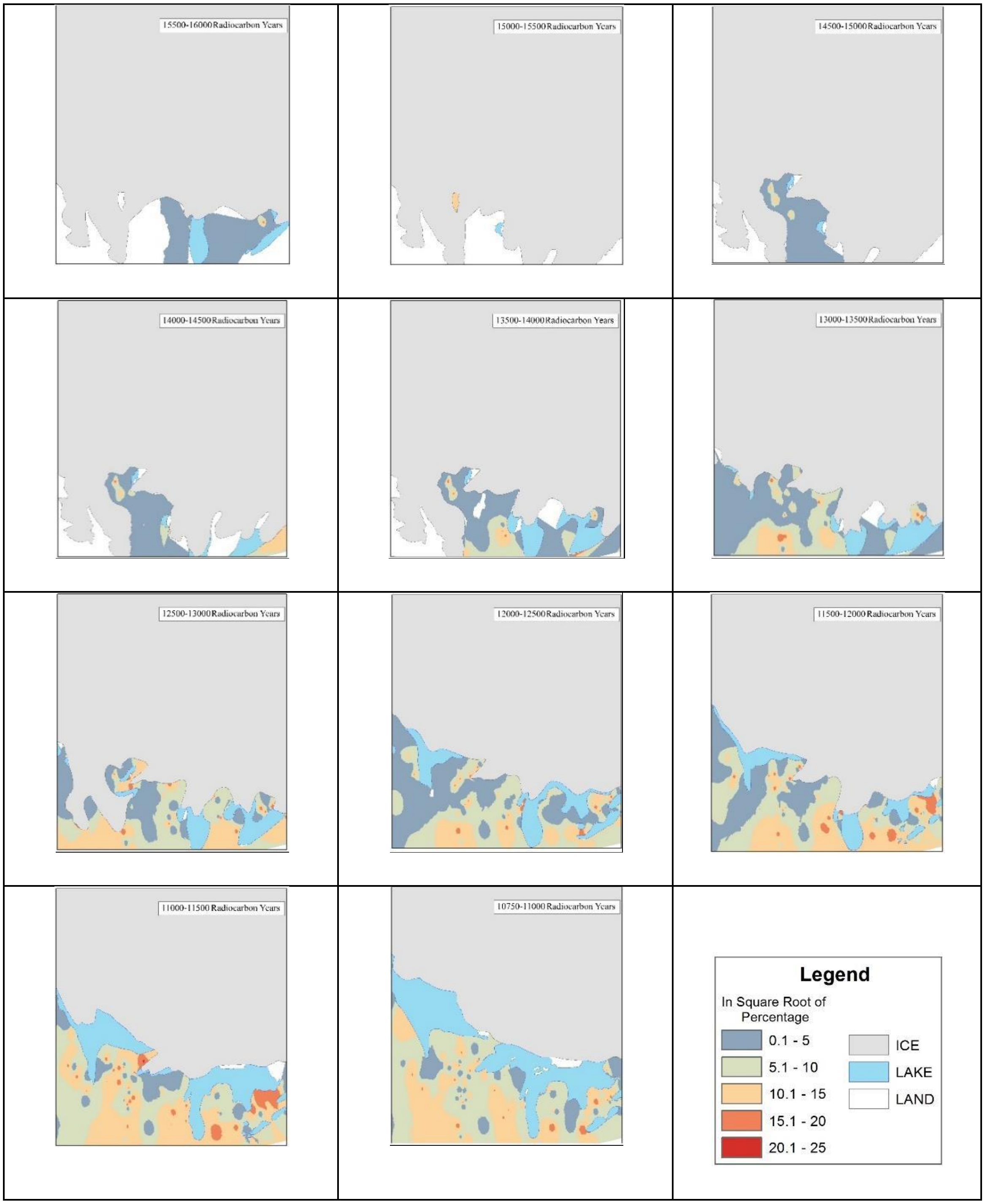


Figure 3.11
Interpolated diagrams that show square root of each pollen percentage and totaled for each time slice with cumulative percentage value of 1-5%, 5-10%, 10-15%, 15-20% and 20-25% as represented by different color codes

Figure 3.11 continued

Chapter IV: DISCUSSION AND CONCLUSION

The result of my study show a general, but not strict, time-transgressive succession of *Picea-Cyperaceae* being replaced by *Pinus-Quercus*. This is well known from the literature (Cushing, 1967; Cushing, 1965; Wright, 1970; Davis, 2000). However, the maps allow us a more detailed and nuanced view of where the habitat probably was. When looked through the maps of each species as *Picea*-Cyperaceae-*Salix* decreases, *Pinus-Quercus* starts to increase in percentage. Also, there is a trend when species get populated in three regions Minnesota, between Lake Ontario and Lake Huron and Northern Michigan from 12,000 ^{14}C yrs. BP and then they start to move apart after 9,000 ^{14}C yrs. BP. Also, the cluster diagrams show the general trend during the same time i.e starting from 11,000 - 9,000 ^{14}C yrs. BP. *Picea-Salix-Cyperaceae*, *Sphagnum*-Ericaceae and *Abies*-Betula appear together. And from 11,000- 13,000 ^{14}C yrs. BP *Salix* is more removed from the *Picea-Cyperaceace* while *Sphagnum*-Ericaceae still persists. Through the interpolated diagrams also, it can be seen that there are three major locations where the percentage presence of all the species except *Pinus* and *Quercus* lie, these regions are also the same region where each species cluster in when looked at each species time-slices maps. Again through interpolated diagrams, the time series for the clustering and declustering goes hand in hand with the cluster diagrams when *Picea-Salix-Cyperacae*, *Sphagnum*-Ericaceae and *Abies-Betula* appear together from 12,000-9,000 ^{14}C yrs. BP.

The sites where the clustering is seen especially in northern Michigan falls where James Fittings, (1968) discovered burnt caribou bones in Holcombe along with Clovis and Preclovis sites stated in Lepper (1999). Therefore, the time and location for prime caribou habitat given the evidence through previous study along with the results from the maps of each species and cluster diagram would be during 11,000-9,000 ^{14}C yrs. BP when the three standard cluster (*Picea-Salix-Cyperacea*, *Sphagnum*-Eriaceae and *Abies-Betula)* appear together. In an earlier period, from 11,000-13000 ^{14}C yrs. BP, *Salix* is more removed yet *Sphagnum*-Ericaceae still appear together, and it is known that Ericaceae family species represent an important winter forage source for caribou and this would represent a favorable caribou habitat. Then again from 9,000 ^{14}C yrs. BP, favorable habitat continues until 8,000 ^{14}C yrs. BP and it moves more towards the north as seen in figure 3.11.

Some of the major events are indeed shown through the abrupt changes in vegetation. The abrupt disappearance of *Salix* from 12,500-12,000 ^{14}C yrs. BP which represents one of the major events called Bølling-Allerød interstadial, which was a warm period followed after the Younger Dryas. With the abrupt change in the *Salix* we can say that this even did effect the caribou population as it is one of the important forage for caribou. Also, as can be seen in figure 13.11 for 9,500- 10,000 ^{14}C yrs. BP, there is lag of what is defined as prime caribou habitat and followed only by favorable caribou habitat. This is the time when Lake Agassiz one of the major freshwater lakes in the world, transgressed followed by the isostatic rebound that occurred more abruptly than any other phases that Teller (2001) defines as Emerson Phase (dated from 9.8-94 ^{14}C yrs. BP).

Also, one of the theories that can be illustrated through the interpolated diagrams would be the Plaid vs Stripes theory stated in Jacobson et al. (1987), where during the late Pleistocene there is a postulated north-south mixed gradient of species and during the Holocene it becomes an east-west orientation. On the interpolated diagrams, it can be seen that during the late Pleistocene, indeed, there was more longitudinal orientation of vegetation zones, while during the Holocene there is a latitudinal orientation. During the longitudinal orientation there was more heterogeneous orientation of floral communities and faunal communities had to move a lot. But during latitudinal orientation, there was homogenous vegetation because of which faunal communities also didn't have to move a lot. As Graham et al. (1967) describes, the caribou managed to survive, while other large species like mammoth and mastodons went extinct, probably because of the caribou adaptations to particular post-glacial habitat and significantly different ecologies and their ability to rapidly adapt to new and shifting vegetational communities. Hence, their presence during the Holocene which is already in east-west orientation is homogenous and similar to present day floral communities.

Another important outcome of this research contributes to our understanding of early human settlements in the Great Lakes Region. Although nearly all of the Paleoindian sites known in Minnesota are located in the southern half of the state(Hijmans and Graham, 2006), there is no ecological reason why human population could not have been also found in the northeastern corner, and also in the regions between Lake Huron and Lake Ontario as well at that time. In fact, prime caribou habitat in the regions mentioned peaked much closer to the first well-documented appearance of humans in the region than in the areas to the south. This would seem to indicate that the reason early Paleoindian sites in northern Minnesota is not found and between Lake Huron and Lake Ontario is because the sties have not yet been discovered, rather than due to some environmentally based factor (e.g. carrying capacity too low, or inadequate post-glacial succession). From these results, archeologist can go onto to hypothesize periods of increased human occupation and specific regions where caribou hunting may have occurred at certain times. Such a hypothesis would do well to advance our current thinking on the subject and provide future research opportunities for decades to come.

References

APG III. (2009). An update of the Angiosperm Phylogeny Group classification for the orderos and families of flowering plants: APGIII. *Botanical Journal of the Linnean Society, 161*, 105-121

Banfield, A. W. (1962). *A revision of riendeer and caribou, genus.* Canada Bull.

Bartlein, P. J., Harrison, S. P., Brewer, S., Davis, B. A., Gajewski, K., Guiot, J., . . . Wu, H. (2011). Pollen-based continental climate reconstruction at 6 and 21 ka: a global synthesis. *Climate Dynamics*, 775-802.

Birks, H. J. (1981). The use of pollen analysis in the reconstruction of past climates: a review. *Climate and History*, 111-138.

Bryson , R. A., & Wendland, W. M. (1967). Tentative climatic Patterns For Some Late Glacial and Post-Glacial Episodes In Central North America. *Life, Land and Water*.

Butzer, K. W. (1971). *Environment and Archaeology: An ecological approach to prehistory, second edition.* Aldine, Chicago.

Chapin III, F. S., & Shaver, G. R. (1985). The Physiological ecology of the North American plant communities. *Springer Neatherlands*, 16-40.

Crowley, T. J. (2000). CLIMAP SSTs re-revisited. *Climate Dynamics*, 241-255.

Cushing, E. J. (1965). Problems in the Quaternary Phytogeography of th Great Lakes Region. In H. E. Wright , & D. G. Frey, *The Quaternary of the United Staes* (pp. 403-416). Princeton University Press.

Cushing, E. J. (1967). Late Wisconsion Pollen Stratigraphy and the Glacial Sequence in Minnesota. In E. J. Cushing , & J. E. Wright, *Quaternary Paleoecology* (pp. 59-88). New Heaven, CT: Yale University Press.

Davis, M. B. (1981a). Quaternary history and stability of forest communities. *Forest succession*, 132-153.

Davis, M. B. (1981b). Quaternary history and the stability of forest communities. *Forest Succession*, 132-153.

Davis, M. B. (2000). Palynology after Y2K-Understanding the source area of pollen in sediments. *Annual Review of Earth and Planetary Sciences*, 1-18.

Donna, A. C., & Wright , H. E. (1979). Forest Change in Minnesota at the End of Pleistocene. *Ecological Monographs*, 1-16.

Dyke, A. S., & Robertson, L. (2003). Deglaciation of North America. *Geological Syrvet of Canada*.

Fieldel, S. J. (1999). Older Than We Thought: Implications of Corrected Dates for Paleoindians. *American Antiquity*, 95-116.

Fittings, J. E. (1968). Environmental Potential and the Post Glacial Readaptation in Eastern North America. *American Antiquity 64*, 441-445.

.

Fittings, J. E., DeVisscher, J., & Wahla, E. J. (1966). *The Paleo-Indian Occupation of Holocombe Beach.* Ann Arbor, Michigan: The University of Michigan Press.

Graham, R. W., & Ernest L, L. (1984). Coevolutionary disequilibrium and Pleistocene Extinctions In P. S. Martin, & R. G. Klein, *Quartenary Extinctions, Prehistoric Revolutions* (pp. 223-249). Tucson, Arizona: The University of Arizona Press.

Graham, R. W., Ernest, L., & Lundelius, J. (1967). Coevolutionary Disequilibrium and Pleistocene Extinctions. In E. J. Cushing, & E. J. Wright , *Quatenary Paleoecology* (pp. 223-248). Yale University Press.

Graumlich, L. J., & Davis, M. B. (1993). Holocene Variation in Spatial Scales of Vegetation Pattern in the Upper Great Lakes Region. *Ecology 74(3)*, 826-839.

Haynes Jr, C. V. (2000). Clovis, Pre-Clovis, Climate Change, and Extinction. *Paleoamerican Origins: Beyond Crisis*, 113-132.

Haynes Jr, C. V. (2005). Clovis, Pre-Clovis, Climate Change and Extinction. *Paleoamerican Origins: Beyond Clovis; A peopling of the Americas Publications*, 113-132.

Hijmans, R. J., & Graham, C. H. (2006). The ability of climate envelope models to predict the effect of climate change on species distribution. *Global Change Biology*, 2272-2281.

Jacobson, G. J., Thompson, W., & Grimm, E. C. (1987). Patterns and rates of vegetation change during the deglacation of eastern North America. *The Geology of North America*, 277-288.

.

Kelsall, J. P. (1968). *The Migratory Barren-Ground Caribou of Canada.* Canadaian Wildlife Service 3: Department of Indian Affairs and Northern Development.

Kutzbach, G. J., Harrison, S., & Behl, P. (1998). Climate and Biome Siumations for the Past 21,000 Years. *Quartenary Science Reviews* , 473-506.

Lepper, B. T. (1999). Pleistocene Peoples of Midcontinental North America. In R. Bonnichsen, & K. L. Turnmire, *Ice Age People of North America* (pp. 362-394). Corvallis, Oregon: Oregon State University Press.

Mix, A. C., & Ruddiman, W. F. (1985). Structure and timing of the last deglacation: oxygen-isotope evidence. *Quaternary Science Reviews*, 59-108.

Moos, M. T., & Cumming, B. F. (2011). Changes in the parkland-boreal forest boundary in northwestern Ontario over the Holocene. *Quaternary Science Reviews*, 1232-1242.

Mulholland, S., Stephen, M. L., Gordon , P. R., Huber, J. K., & Moores, H. D. (1997). Paleo-Indian Occupation in Northeastern Minnesota: How Early? *North American Archaeologist*, 371-400.

Neotomadb.org. (2015, December 15). *Neotoma Paleoecology database*. Retrieved from http://www.neotomadb.org/: http://ceiwin5.cei.psu.edu/Neotoma/Explorer/

Osborn, H. F. (1910). *The age of mammals.* New york.

Peterson, G. M., Kutzbach, T., Hammen, V. D., Wijmstra, T. A., & Street, F. A. (1979). The continental record of environmental conditions at 18,000 yr BP: an initial evaluation. *Quaternary Research*, 47-82.

Ritchie, J. C., Cwynar, L. C., & Spear, R. W. (1983). Evidence from norh-west Canada for an early Holocence Milankovitch thermal maximum. *Nature*, 126-128.

Rowe, J. S. (1959). *Forest Regions of Canada.* Bull, Ottawa: Department of Northern Affairs Natural Resource, Forestry Branch.

Shelford, V. E. (1963). *The Ecology of North America.* Urbana: University of illinios Press.

Storck , P. L., & Speiss, A. E. (1994). The Significance of new Faunal Identifications Attributed to and Early Paleoindian(Gainey Comples) Occupations at th Udora Site, Ontario, Canada. *American Antiquity 59*, 121-142.

Storck, P. L. (1988). The Late Wisconsinan Ice Margin and Early Paleo-Indian Occupation in the Mid-Continent Region. *Midcontinental Journal of Archaeology*, 259-272.

Teller, J. T. (1987). Proglacial lakes and the southern margin of the Laurentide Ice Sheet. *North America and adjacent oceans during the last deglaciation, 3*, 39-69.

Teller, J. T. (2001). Formation of large beaches in an area of rapid differential isostatic rebound: the three outlet control of Lake Agassiz. *Quaternary Science Reviews*, 1649-1659.

Teller, J. T., Boyd, M., Yang, Z., Kor, P. S., & Mokhtari, F. (2005). Alternative routing of Lake Agassiz overflow during the Younger Dryas: new dates, paleotopography and reevaluation. *Quaternary Research*, 87-108.

Theler, J. L., & Boszhardt, R. F. (2003). *Twelve Millennia: Archaeology of the Upper Mississippi River Valley.* Iowa City, IA: University of Iowa Press.

Vitt, D. H., & Slack, N. G. (1984). Niche diversification of Sphagnum relative to environmental factors in northern MInnesota peatlands. *Canadian Journal of Botany, 62*, 1409-30.

Von, L. P. (1946). The prospects for pollen analysis in the study of Earth's climatic history. *New Phytologist*, 193-217.

Watts, W. A. (1967). Late-Glacial Plant Macrofossils from Minnesota. In E. J. Cushing, & H. E. Wright, *Quaternary Paleocology* (pp. 88-97). New Haven, CT: Yale University Press.

Williams, J. W., Shuman, B. N., Webb III, T., Bartlein, P. J., & Leduc, P. L. (2004). Late-Quaternary Vegetaion Dynamics in North America: Scaling from taxa to biomes. *Ecological Monographs*, 309-334.

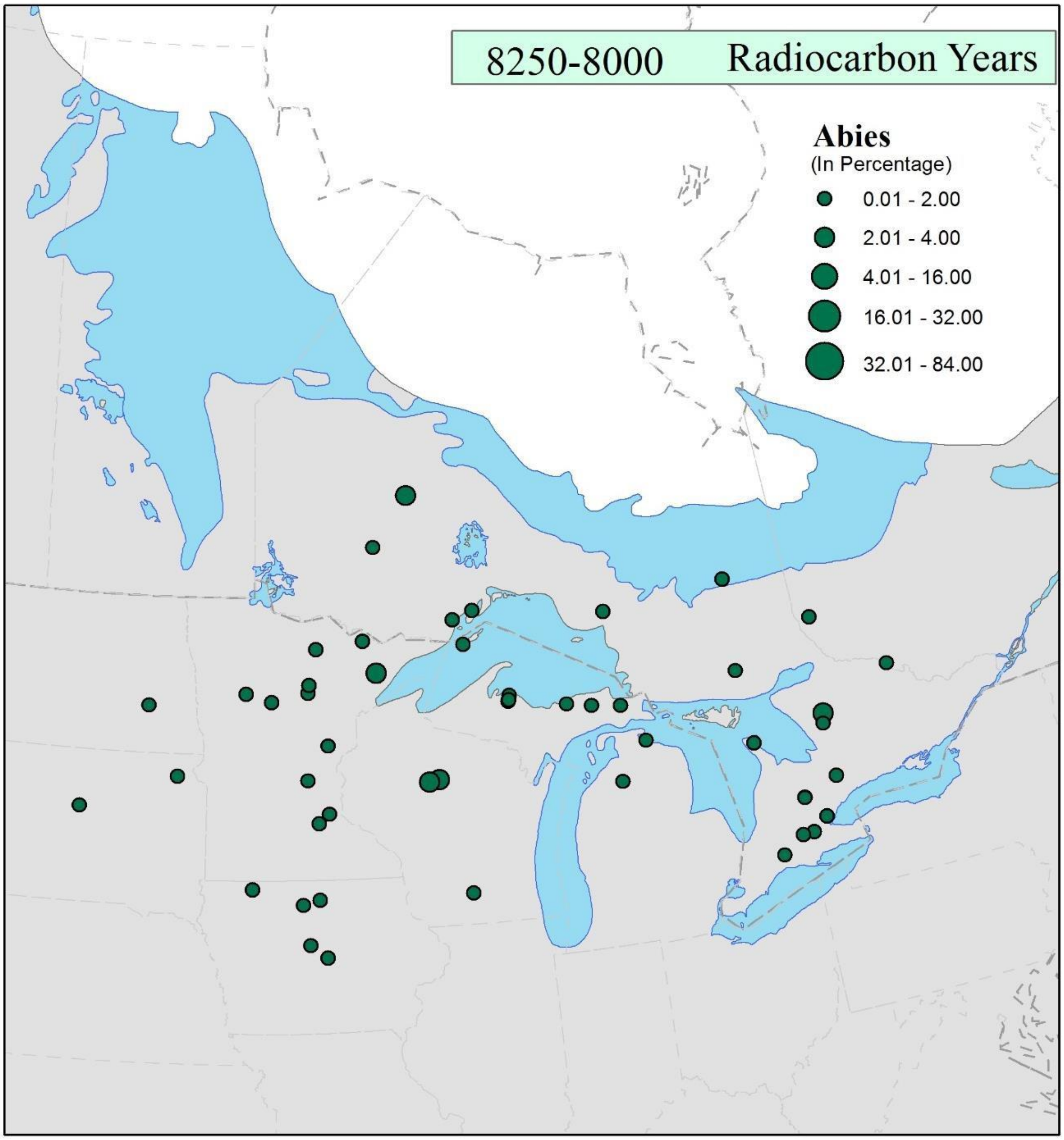
Wright, H. E. (1968). History of the prairie peninsula . In R. E. Bergstron, *The Quaternary of Illinois* (pp. 78-88). Urbana, College of Agriculture: University of Illinois Special Publication.

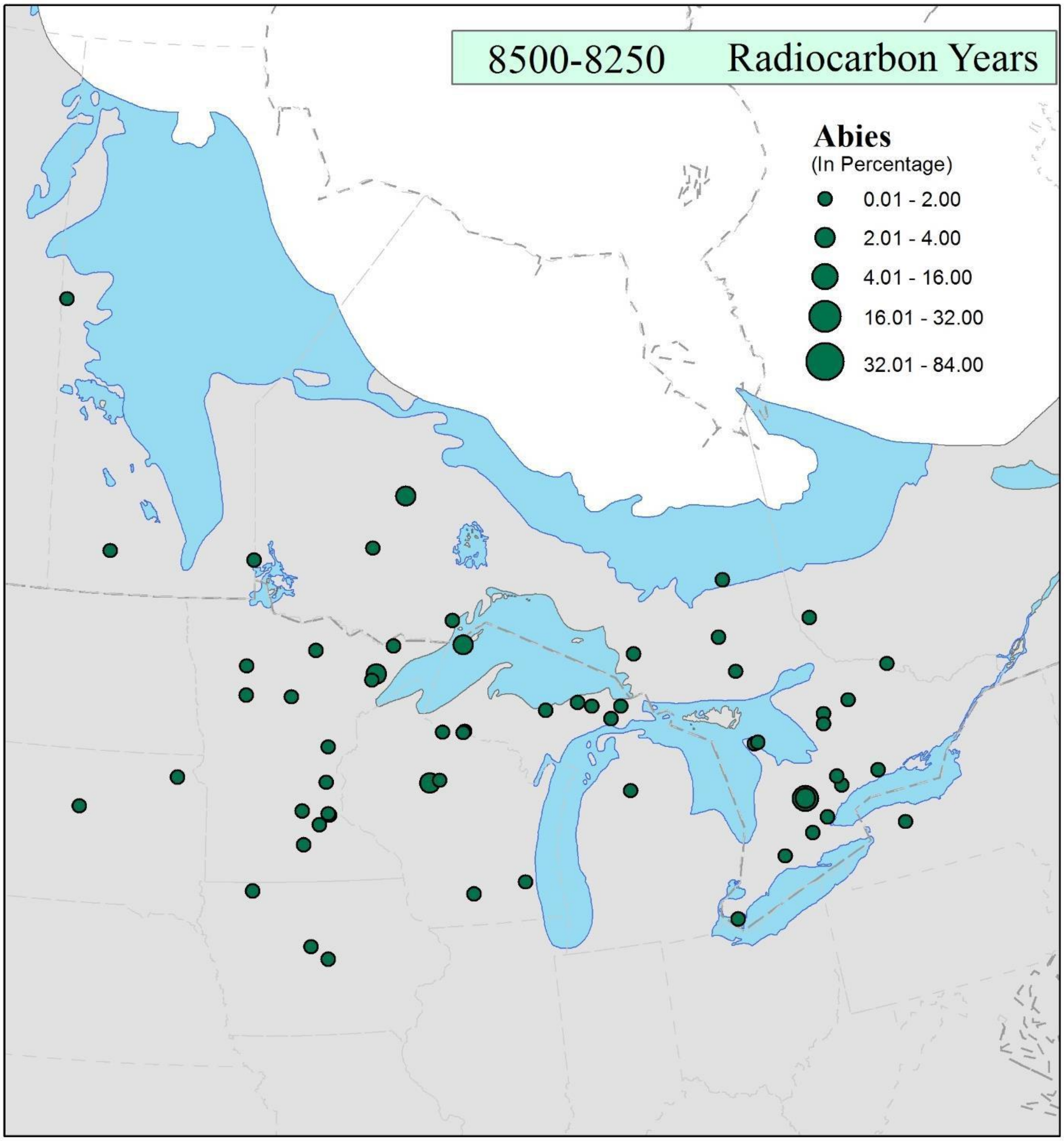
Wright, H. E. (1970). A vegetational history of the central Plains. In W. J. Dort, & J. K. Jones, *Pliestocene and Recent envrionements of the central Great Plains* (pp. 157-172). Lawerence: University of Kansas Press.

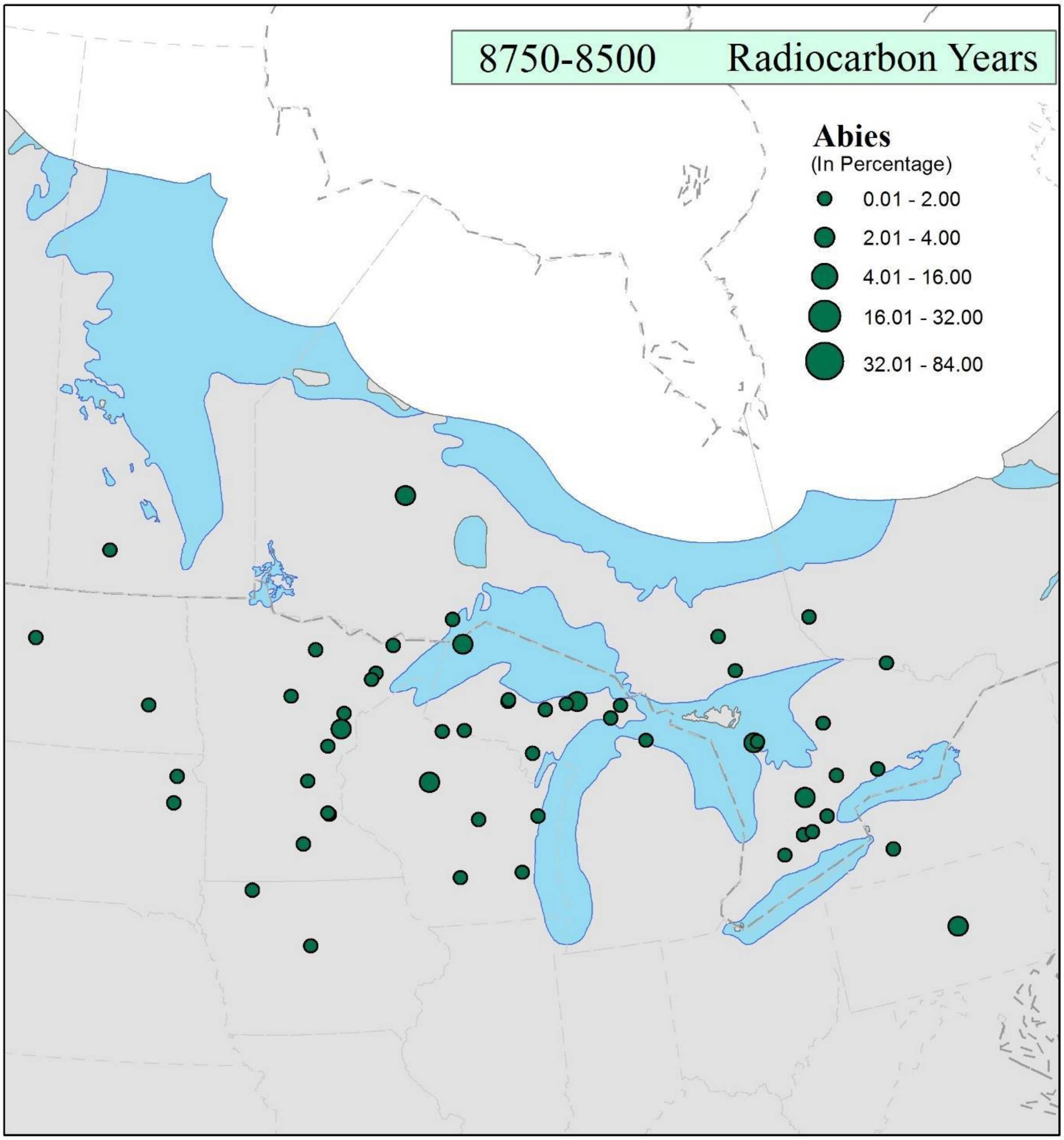
Yu, Z. (2000). Ecosystem response to Lateglacial and early Holocene climate oscillations in the Great Lakes region of North America. *Quaternary Science reviews*, 1723-1747.

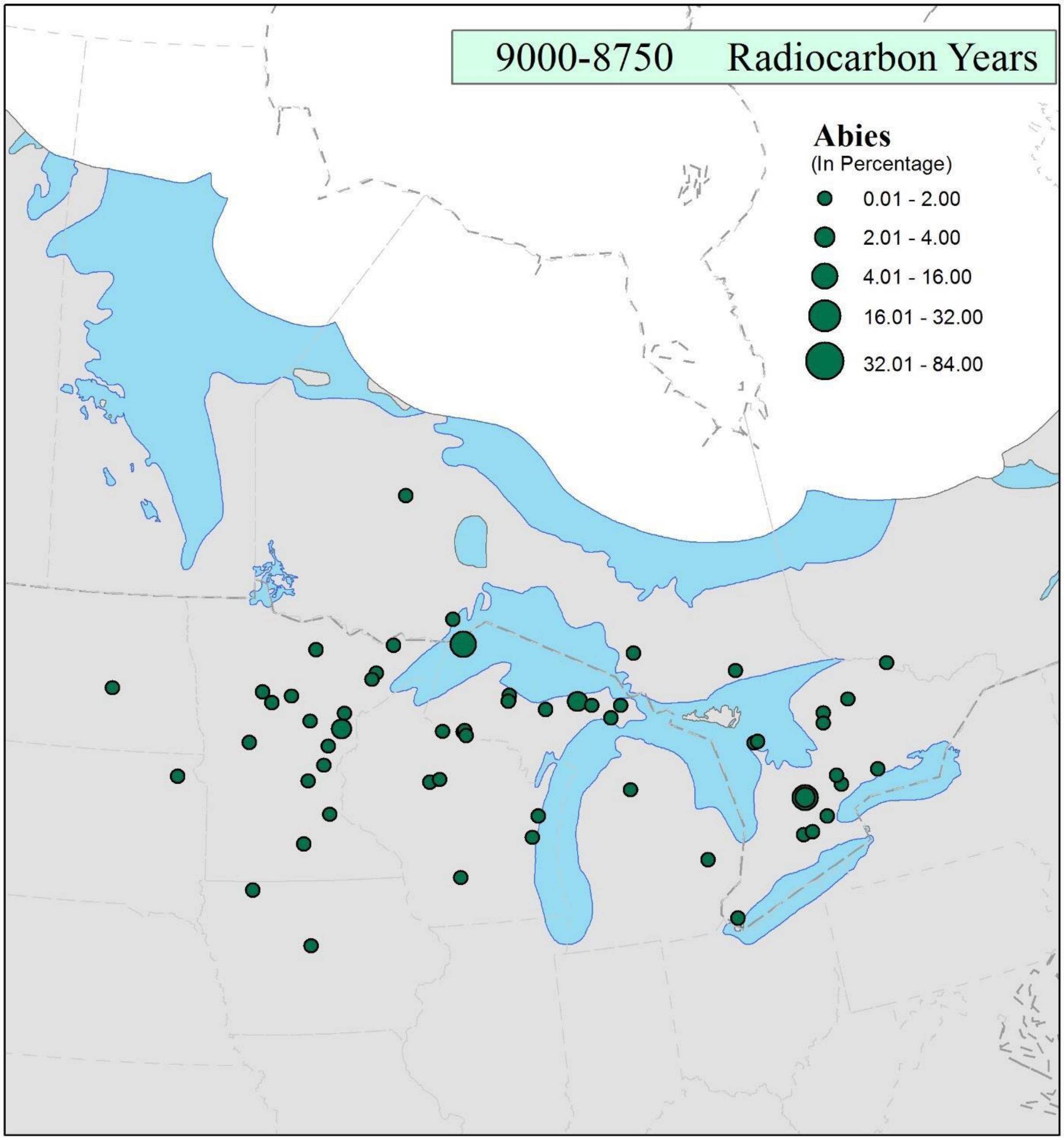
Appendix I

Pollen abundance of *Abies*

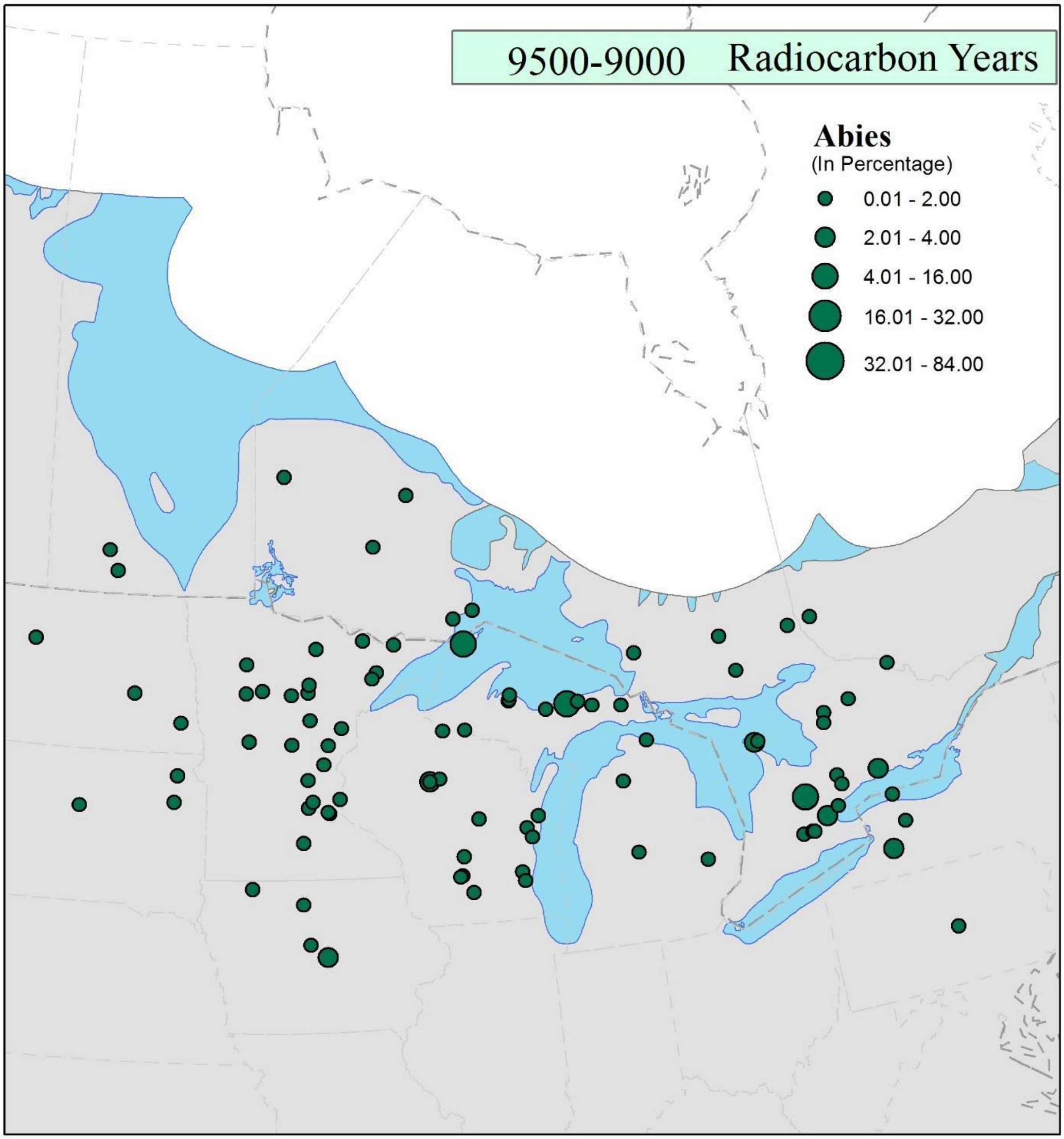

8250-8000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

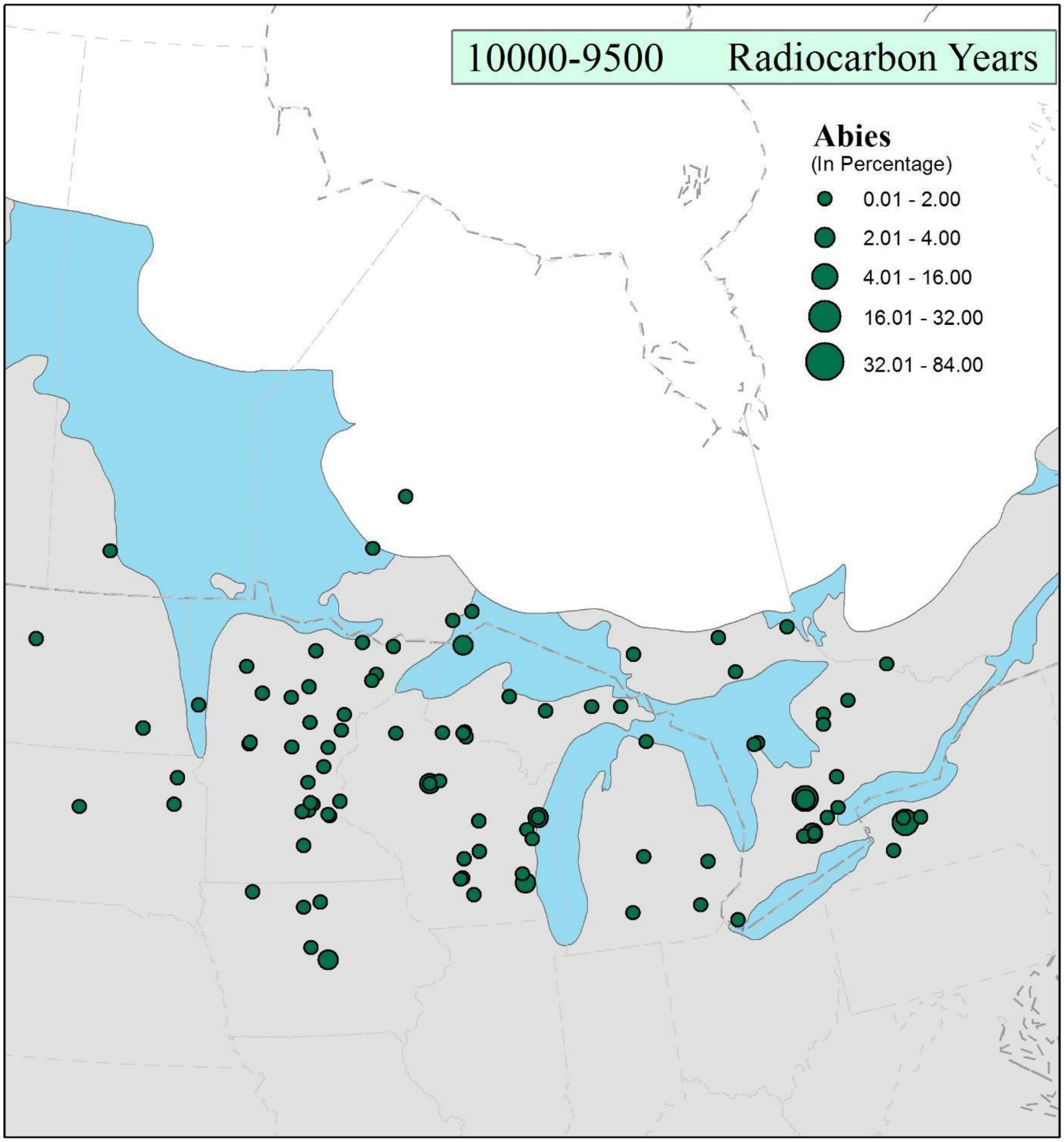

8500-8250 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

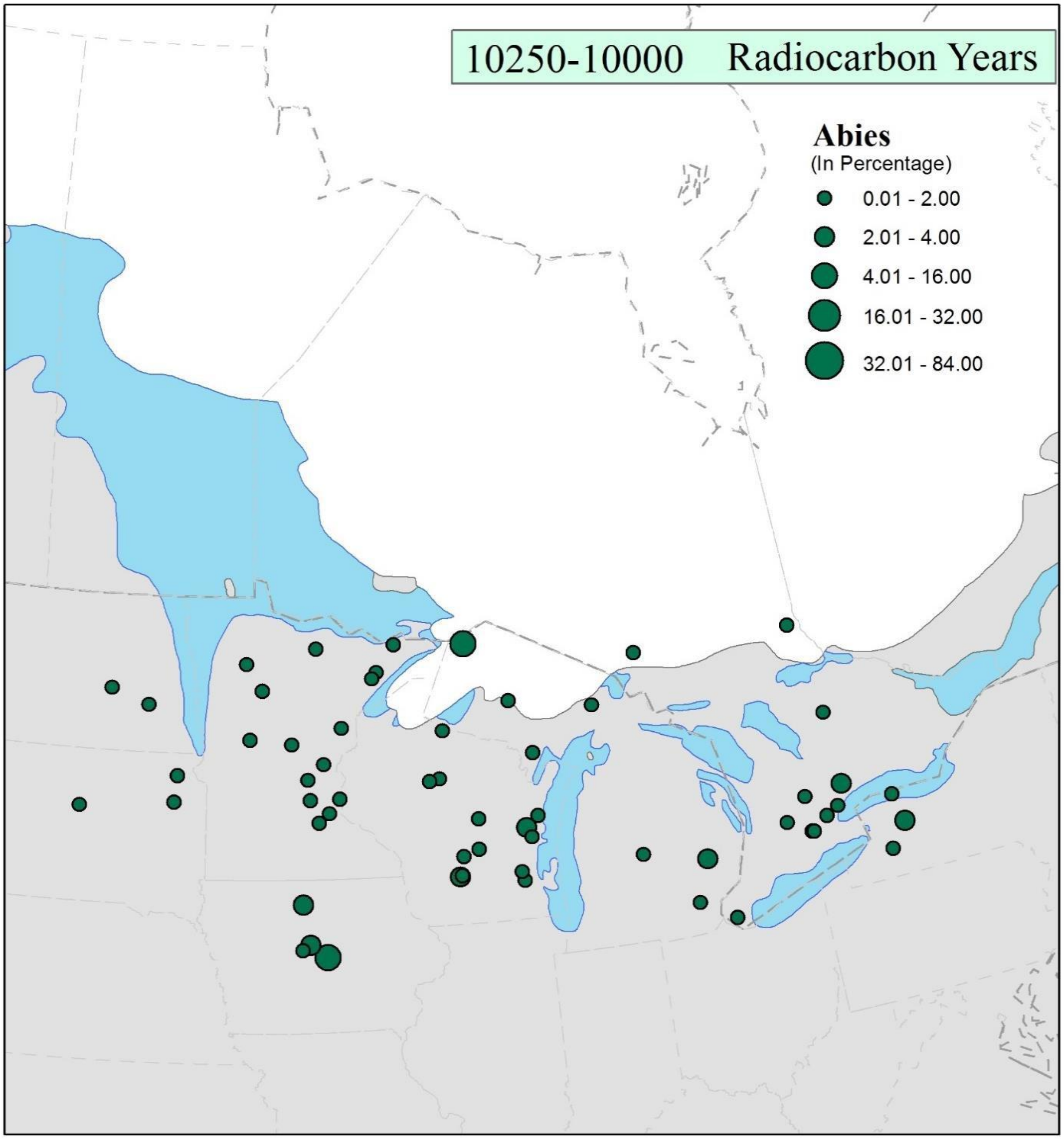

8750-8500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

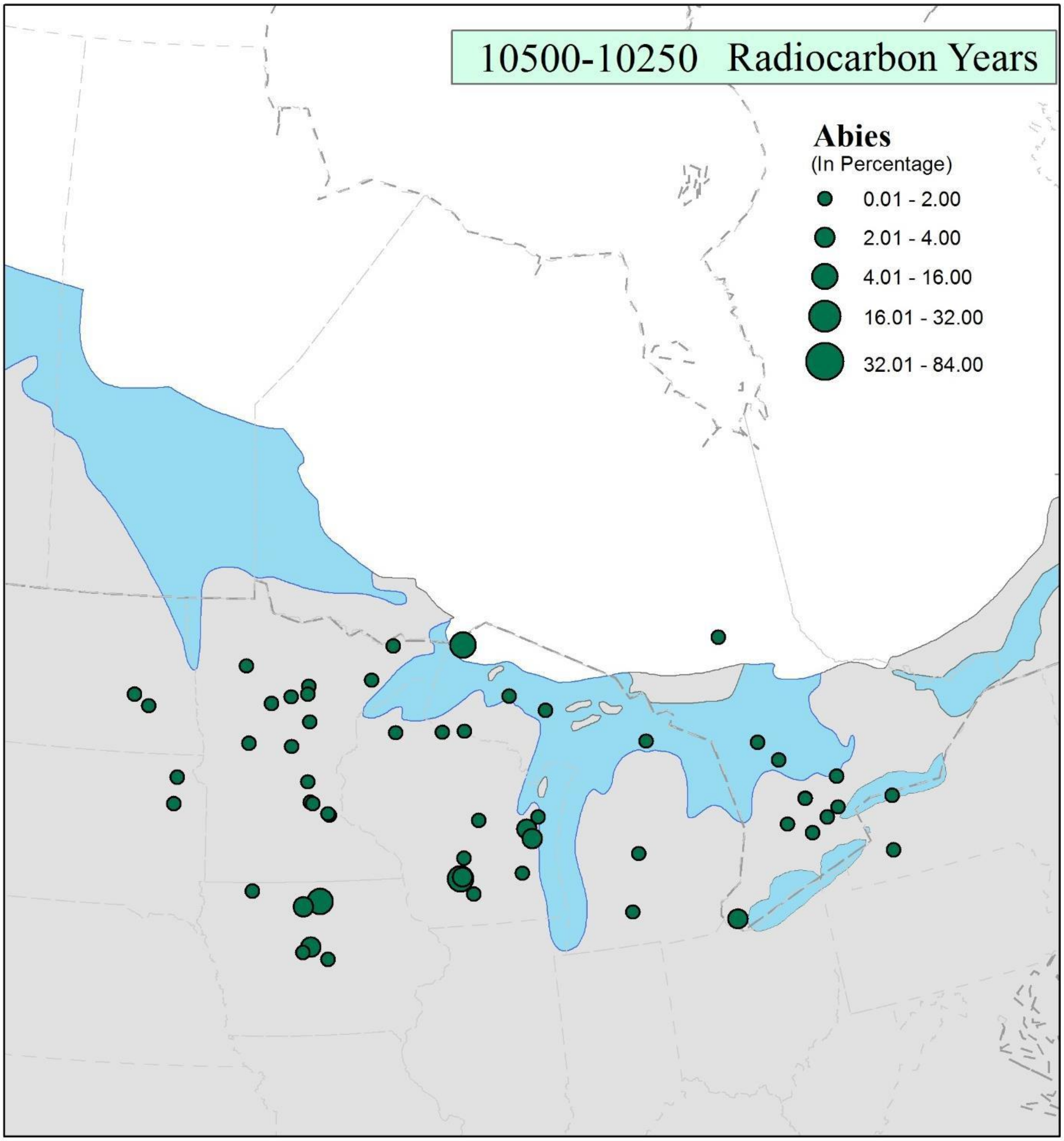


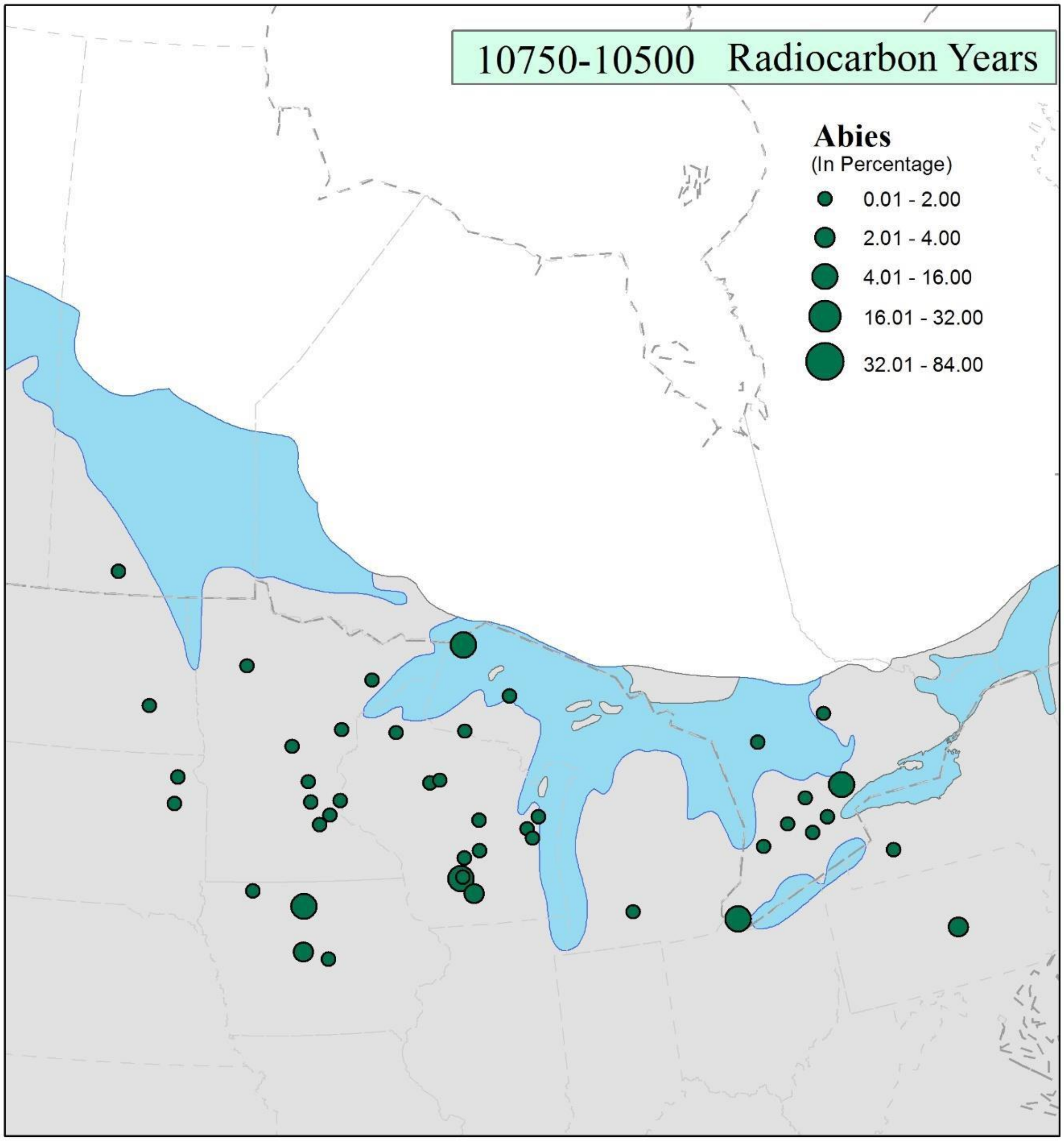
9000-8750 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

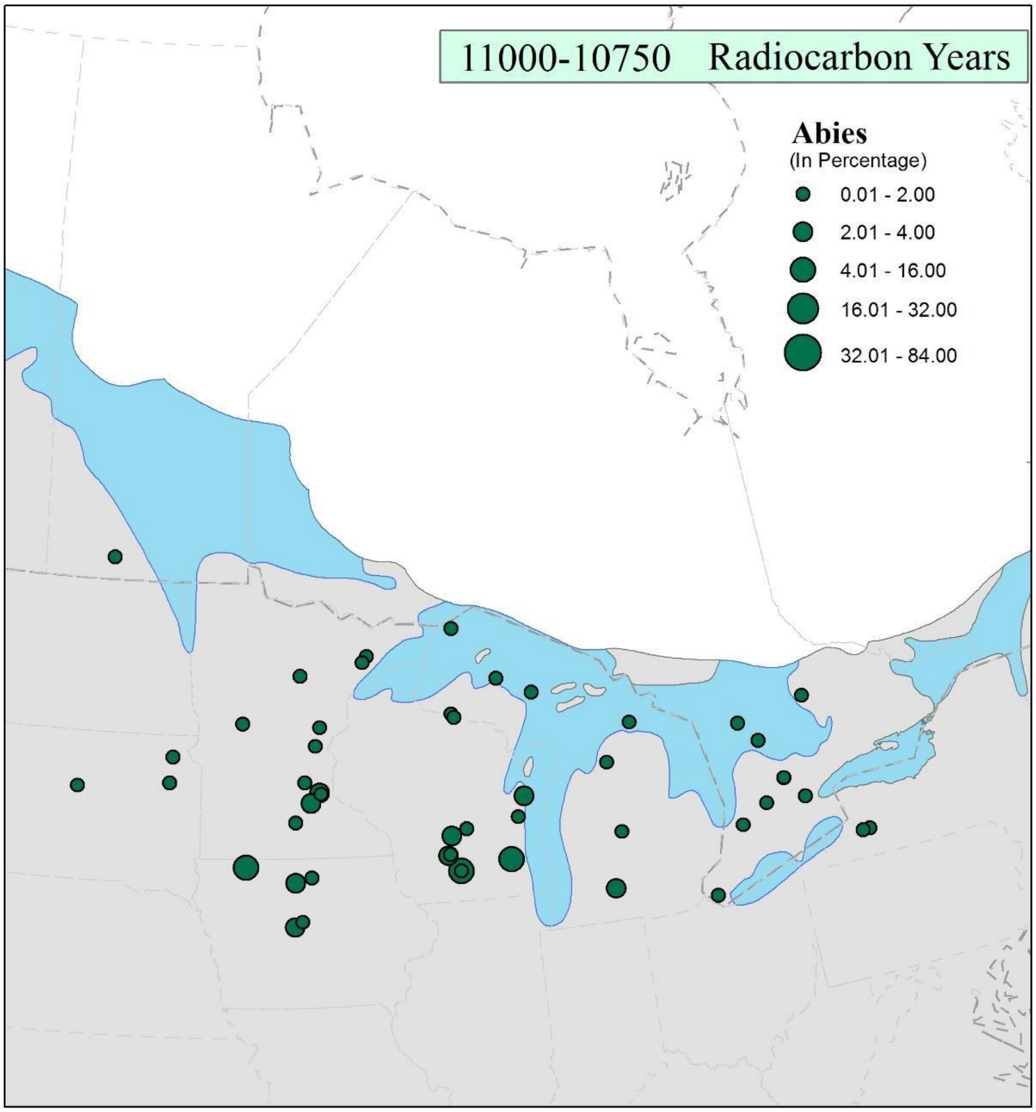

9500-9000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


10000-9500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

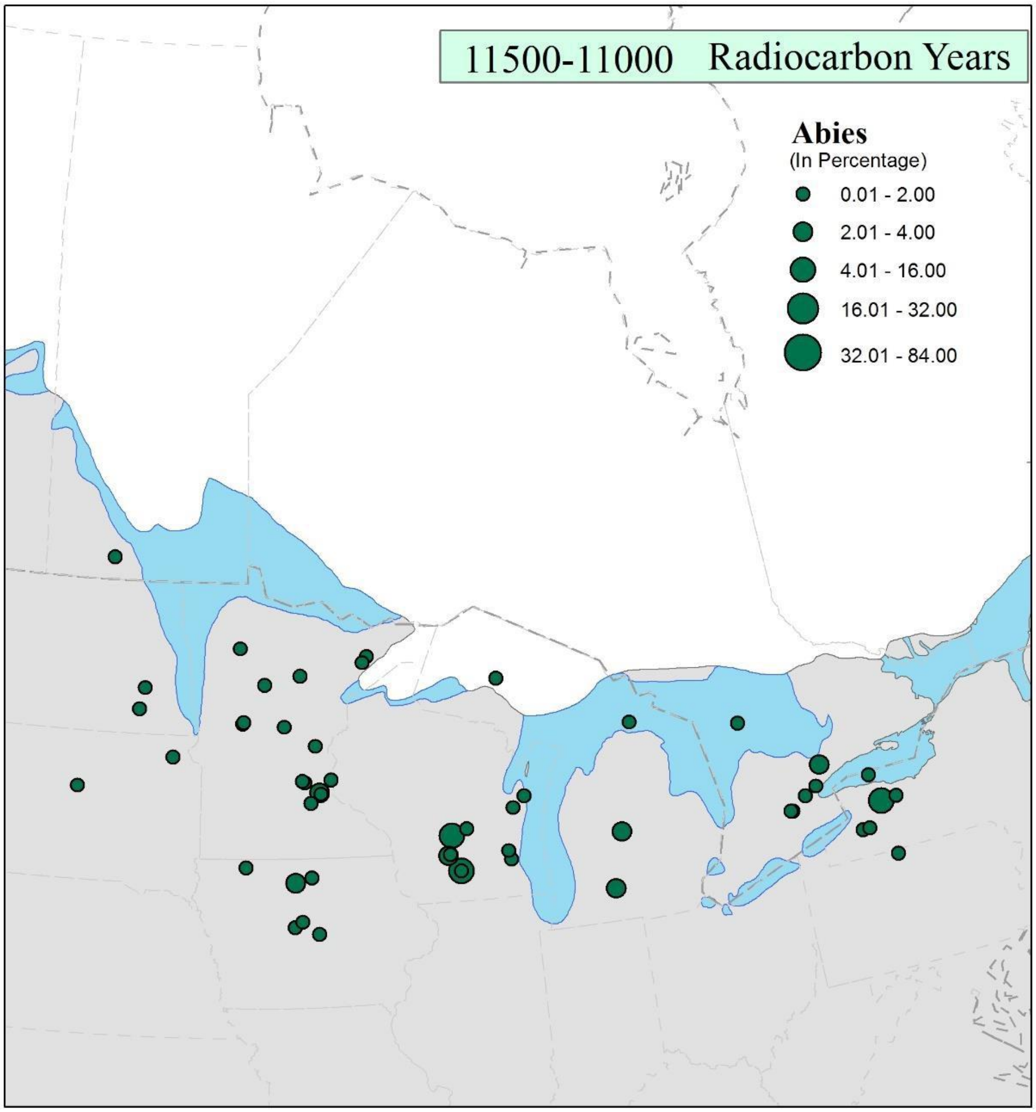

10250-10000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

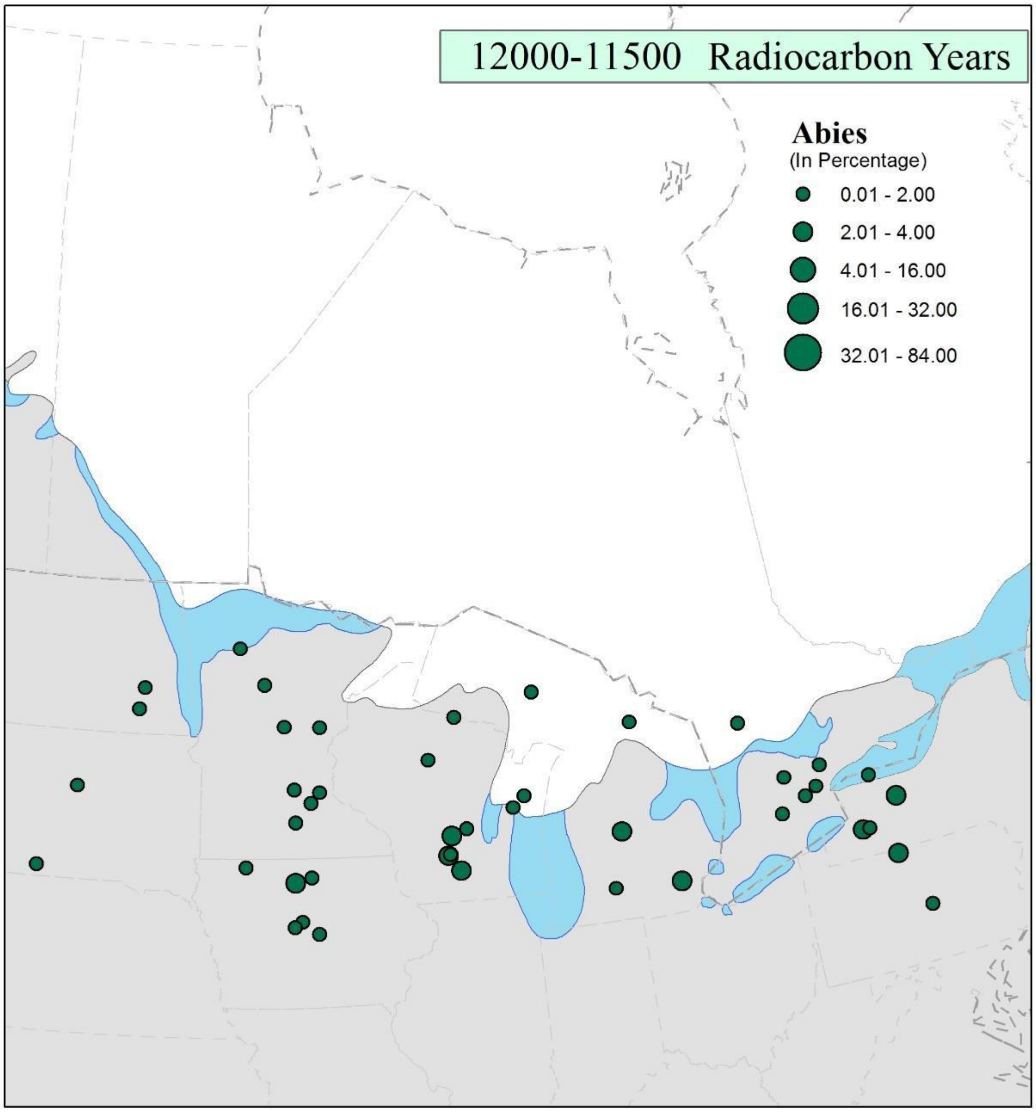

10500-10250 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

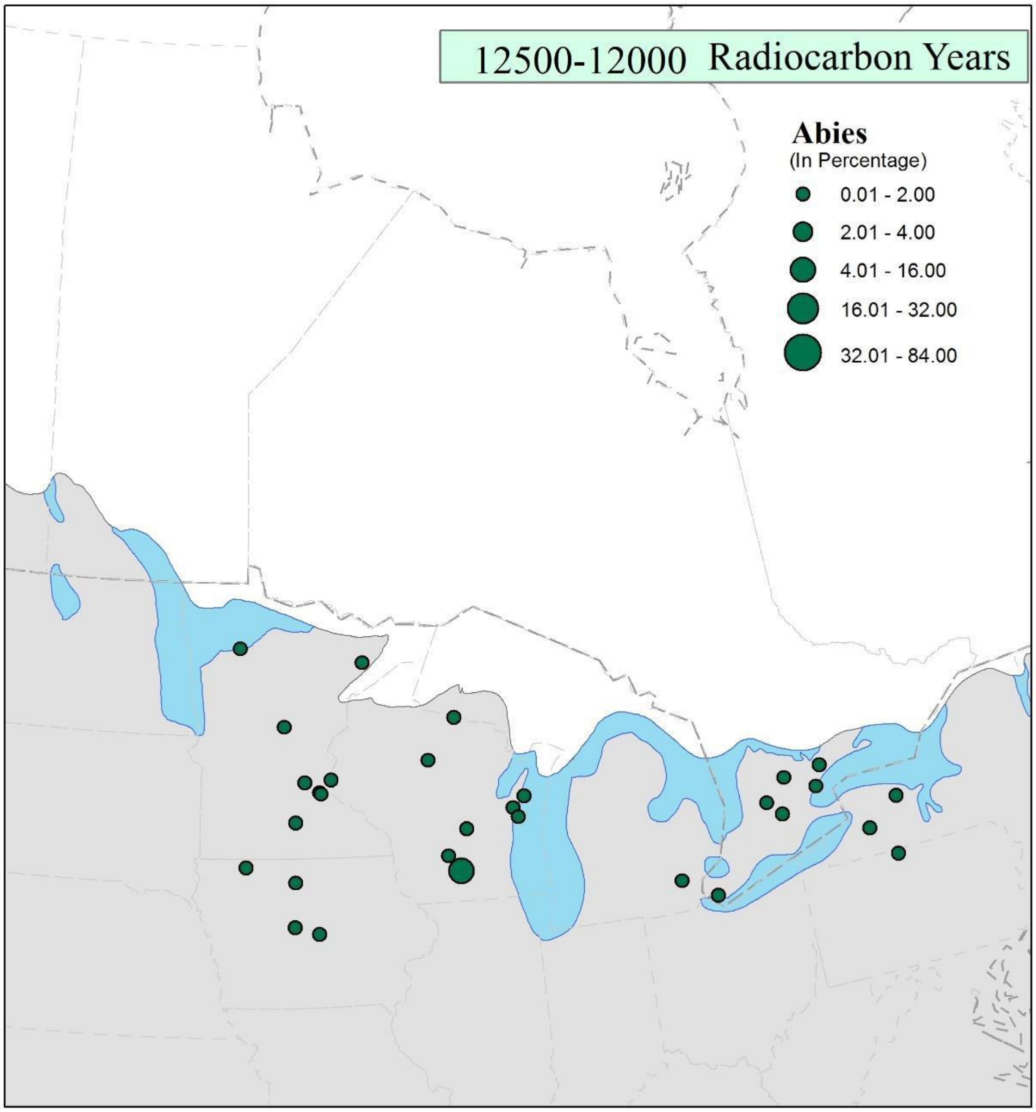

10750-10500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

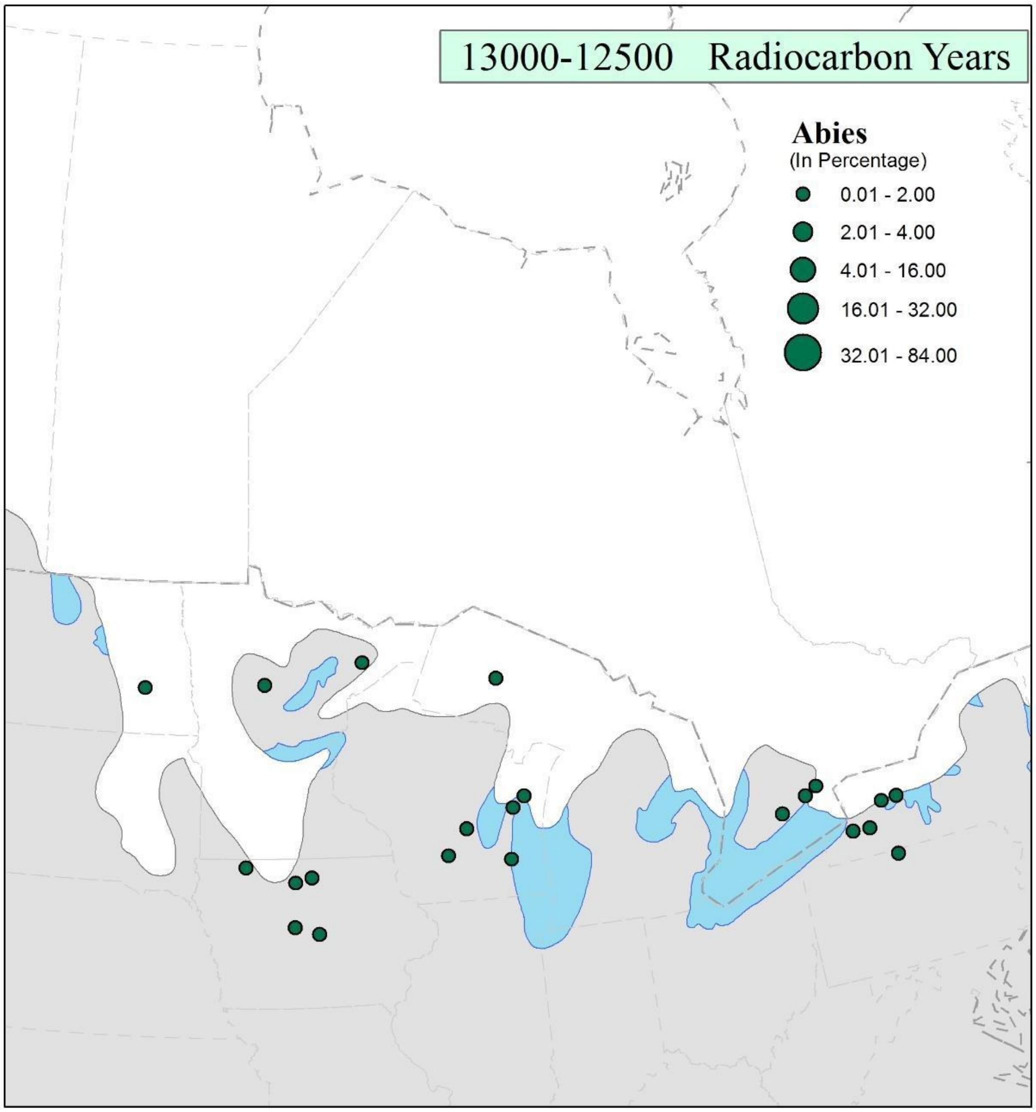


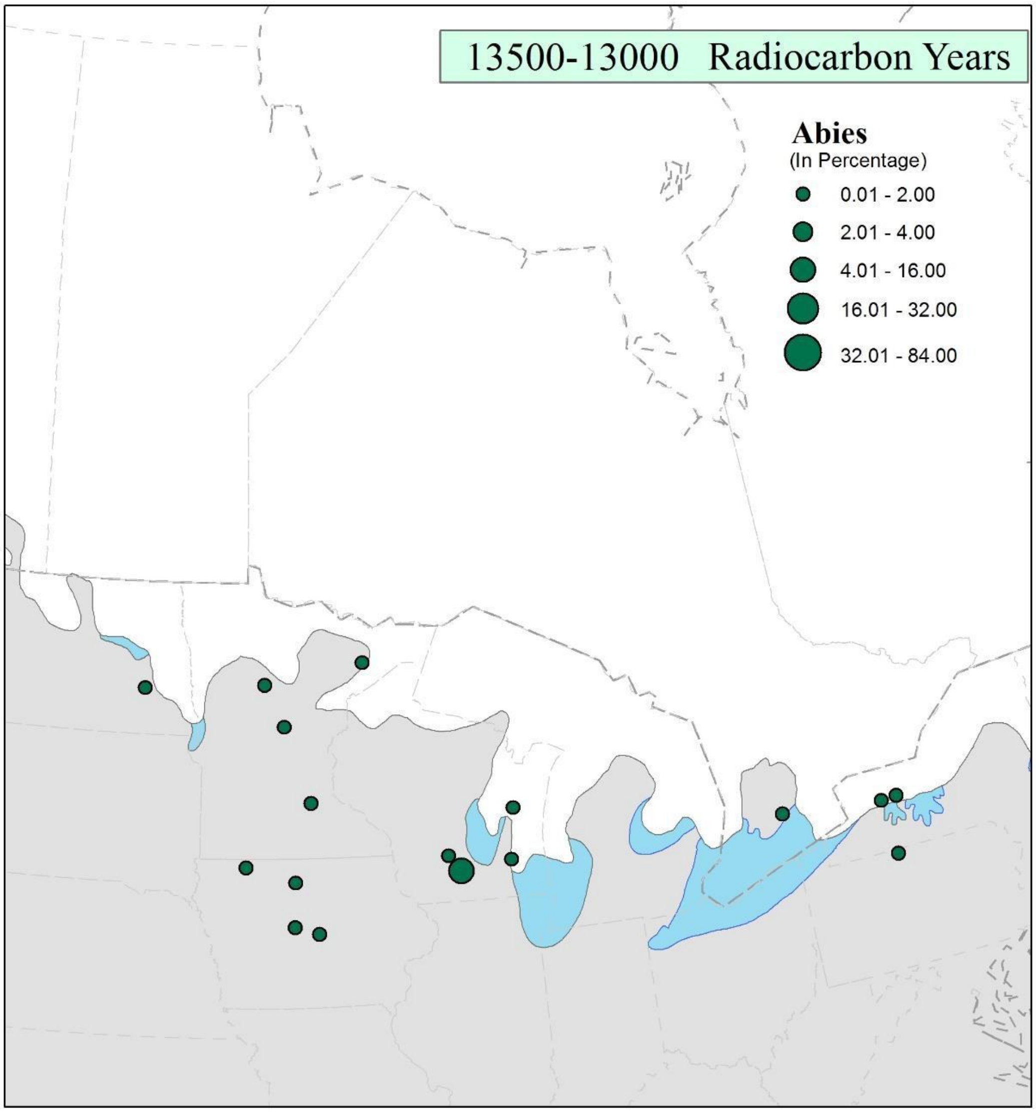
11000-10750 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

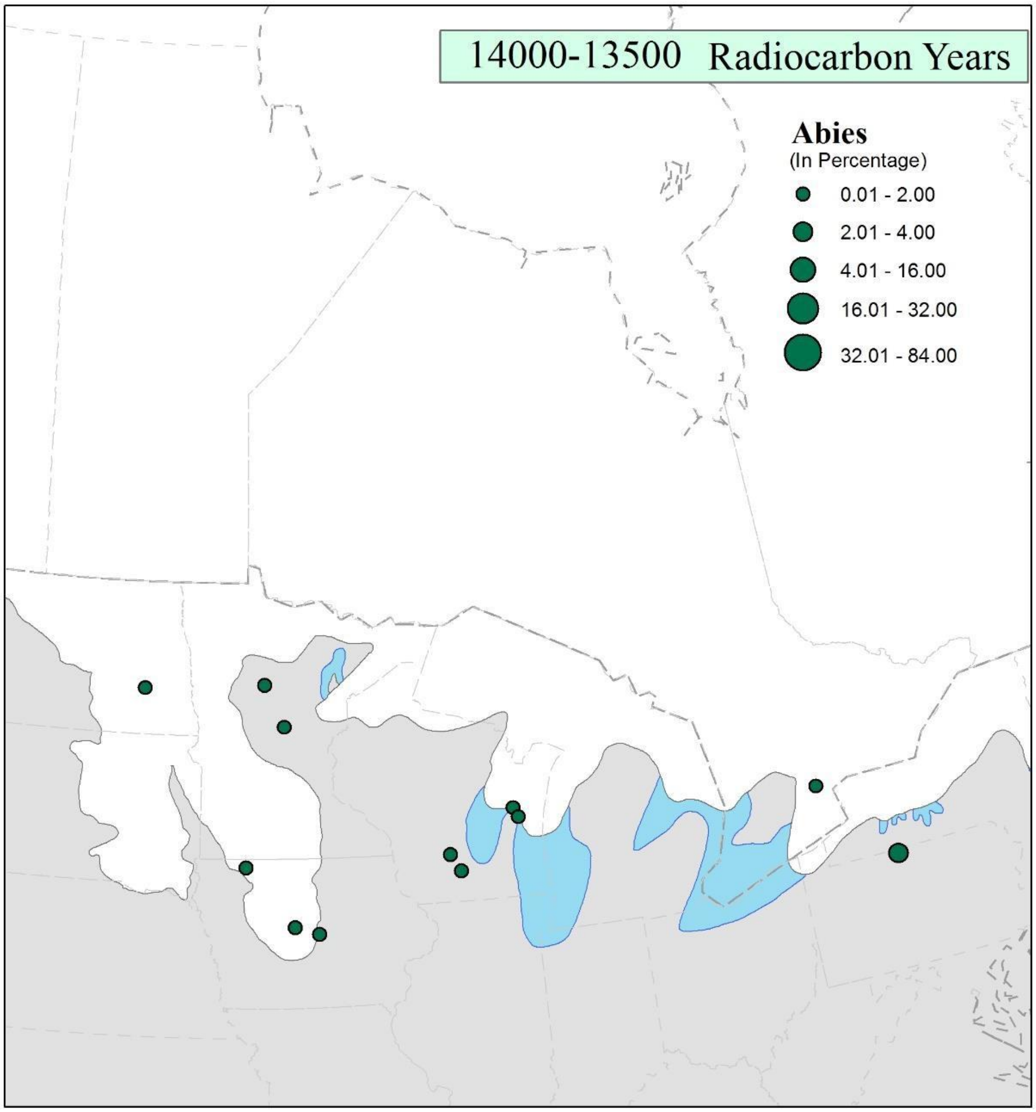

11500-11000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

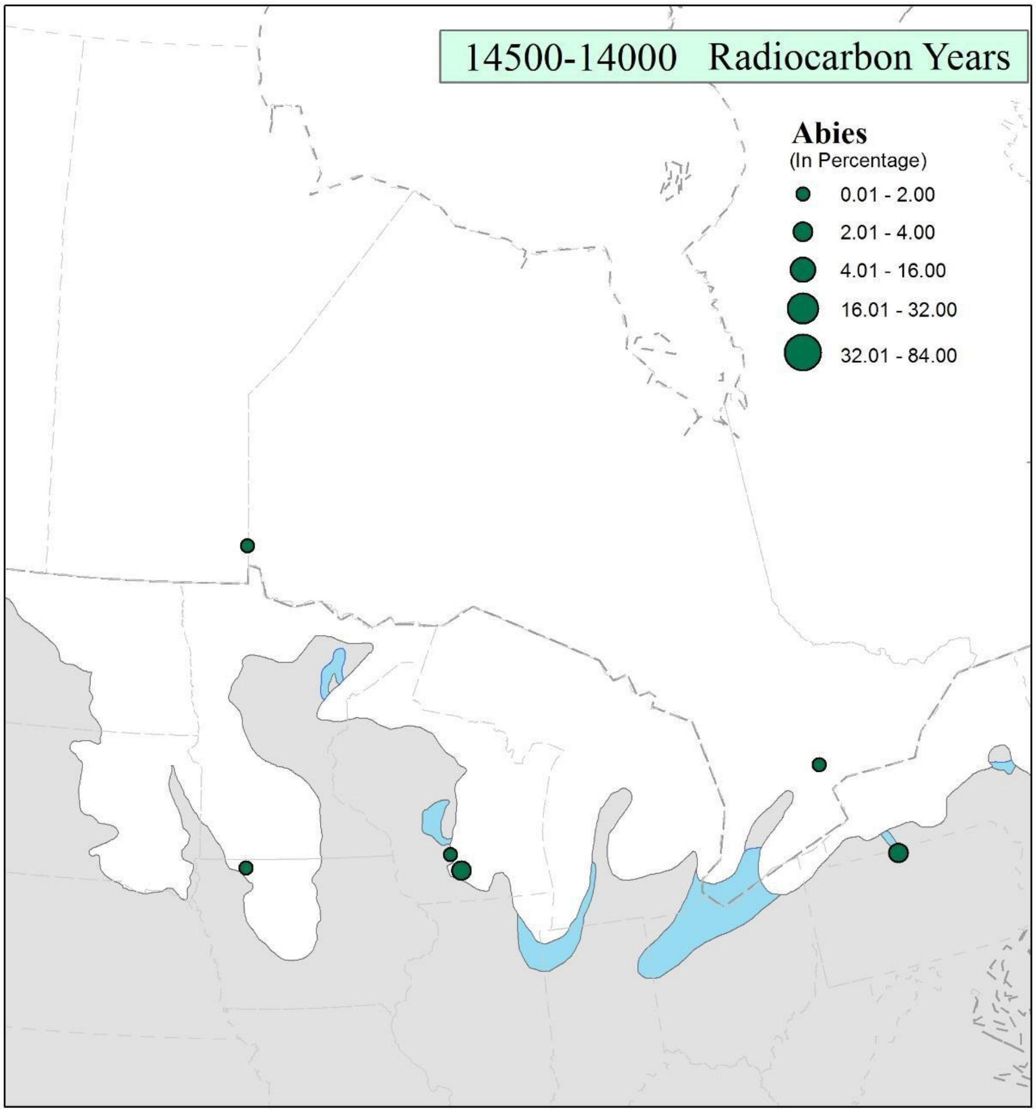

12000-11500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

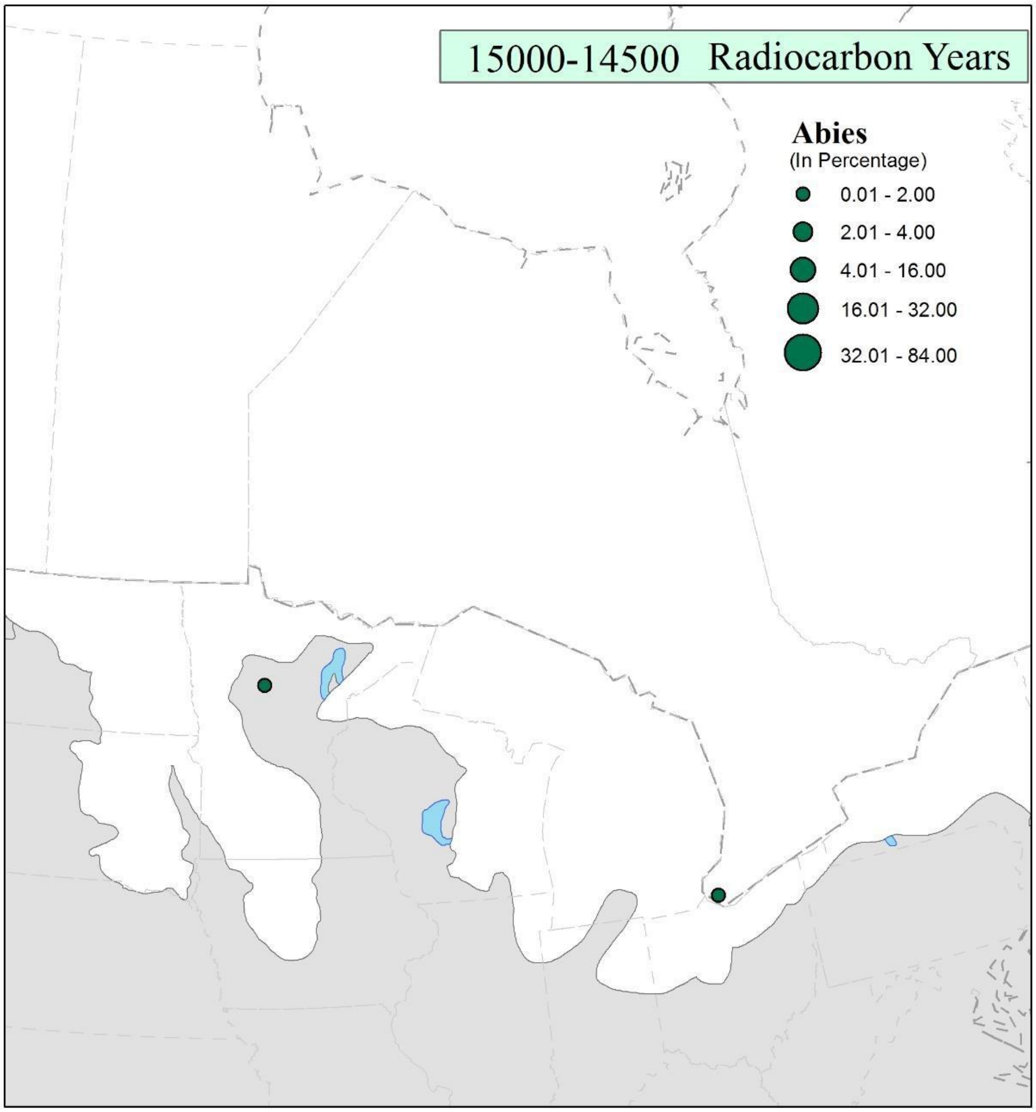

12500-12000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

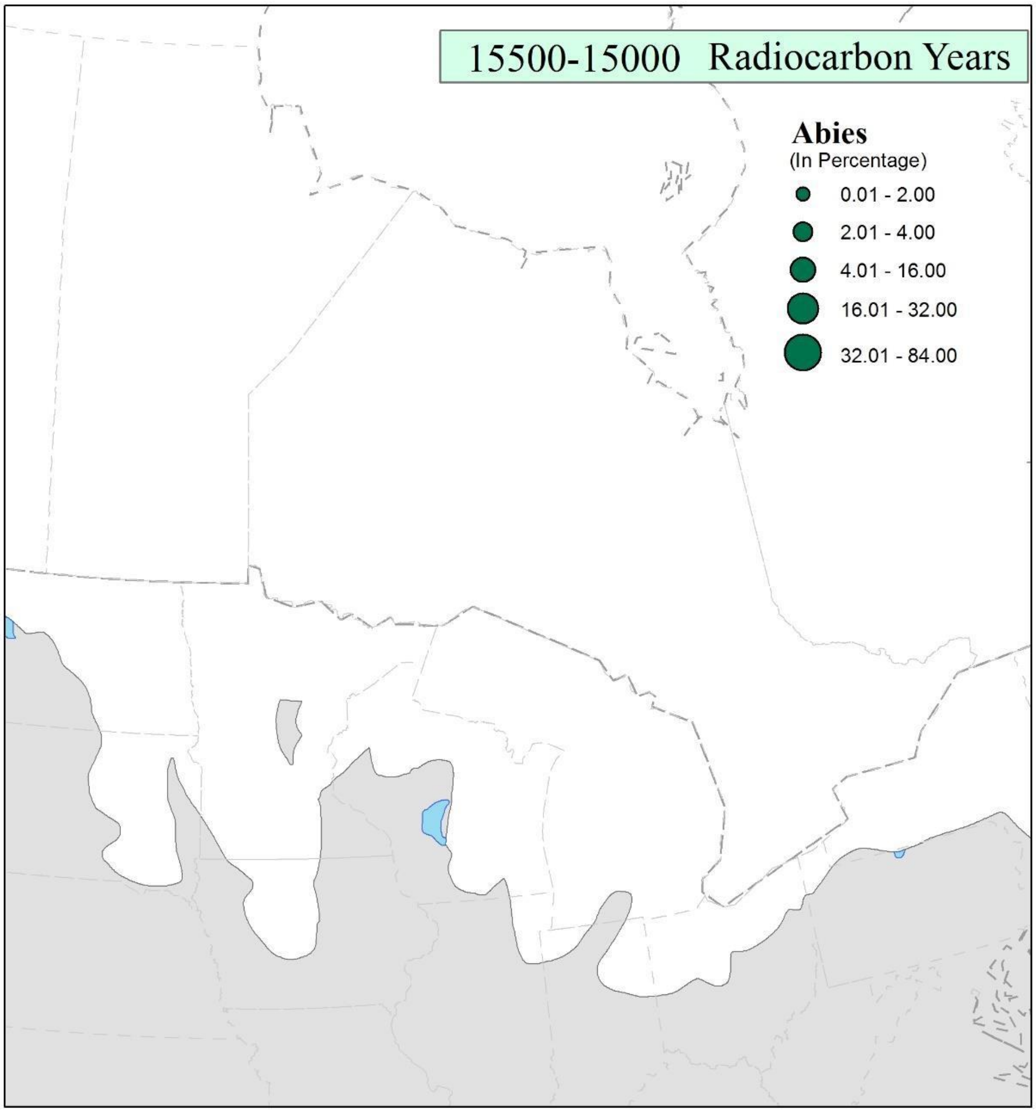

13000-12500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

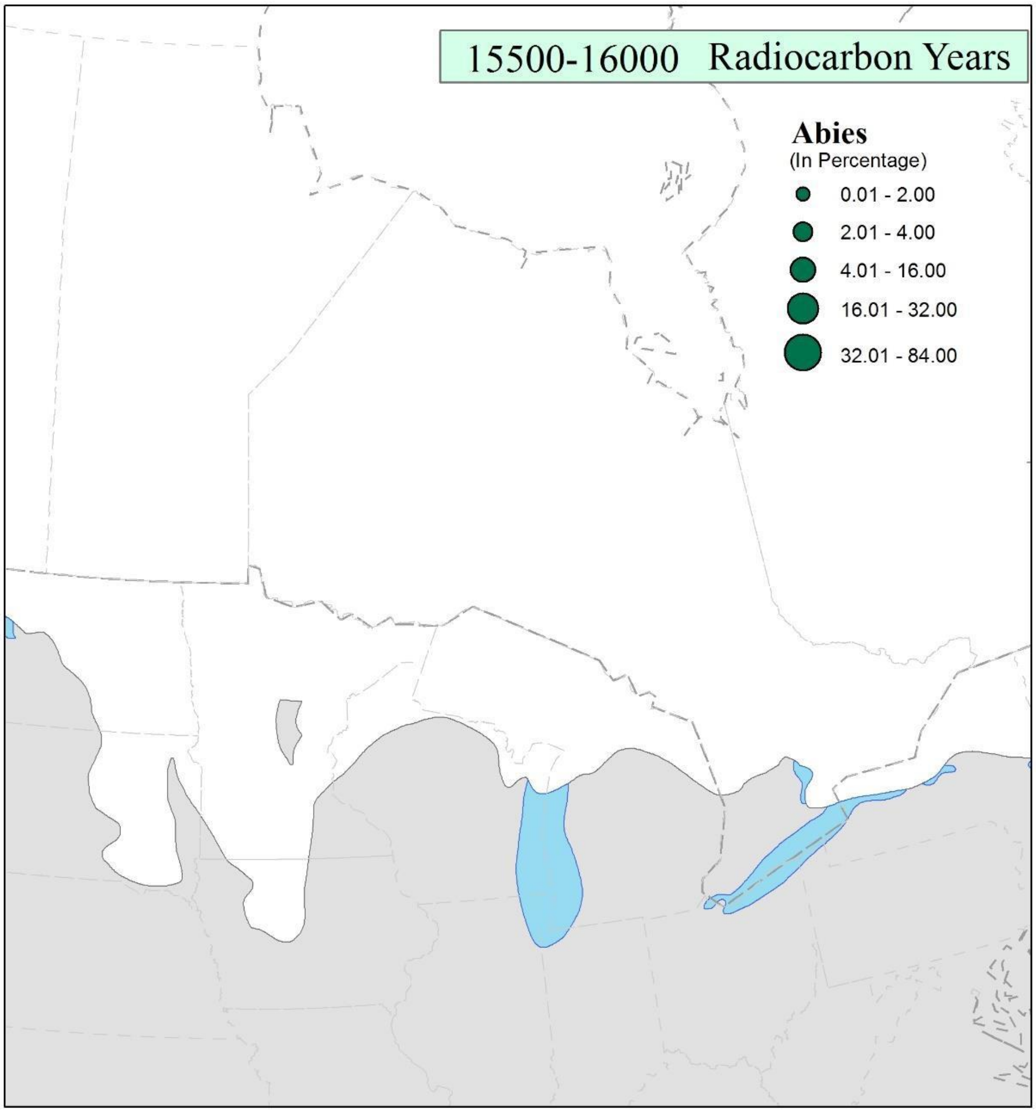

13500-13000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14000-13500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14500-14000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

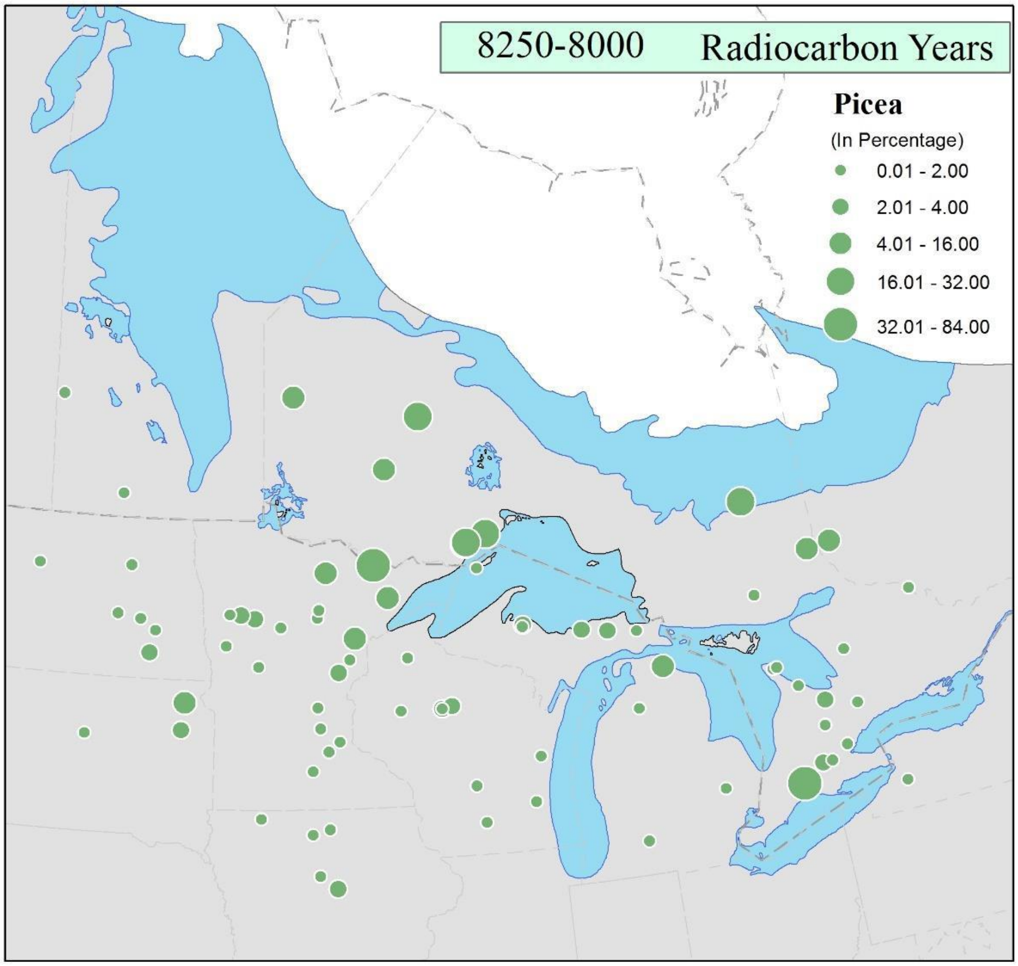

15000-14500 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

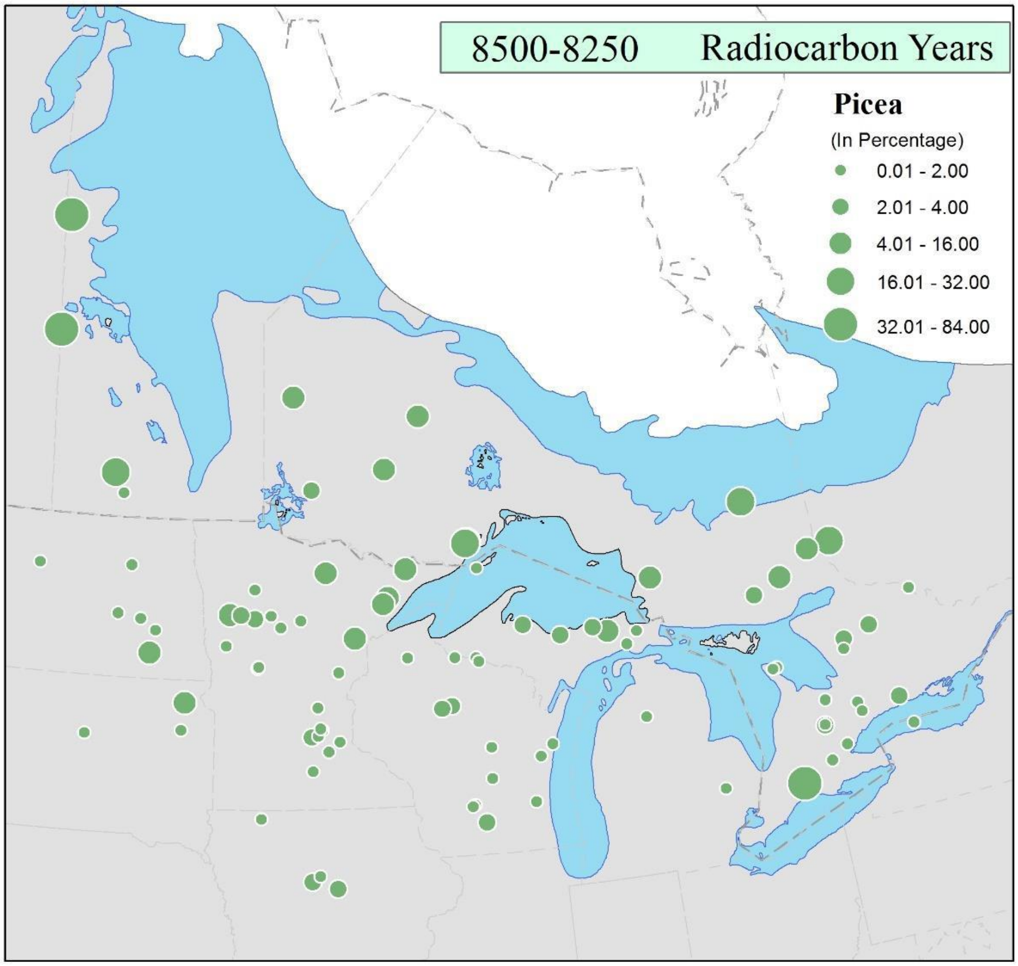

15500-15000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

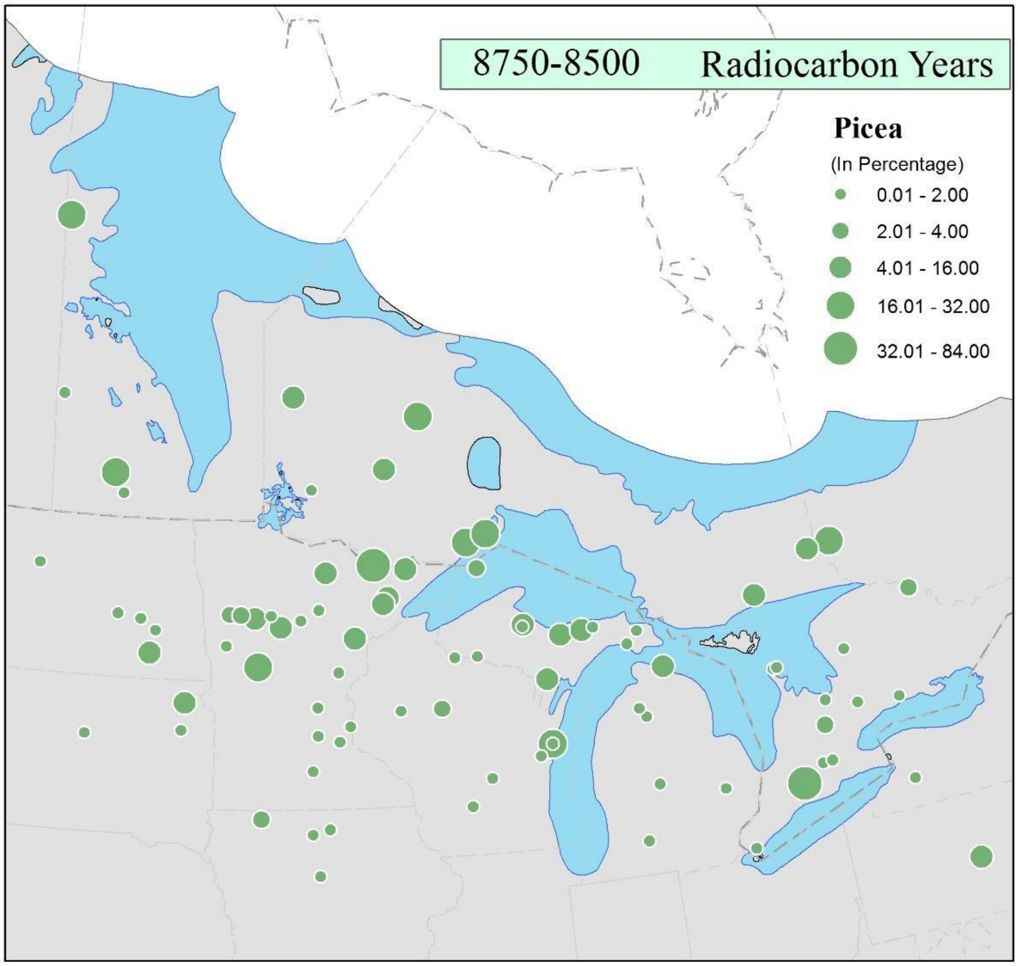

15500-16000 Radiocarbon Years
Abies
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

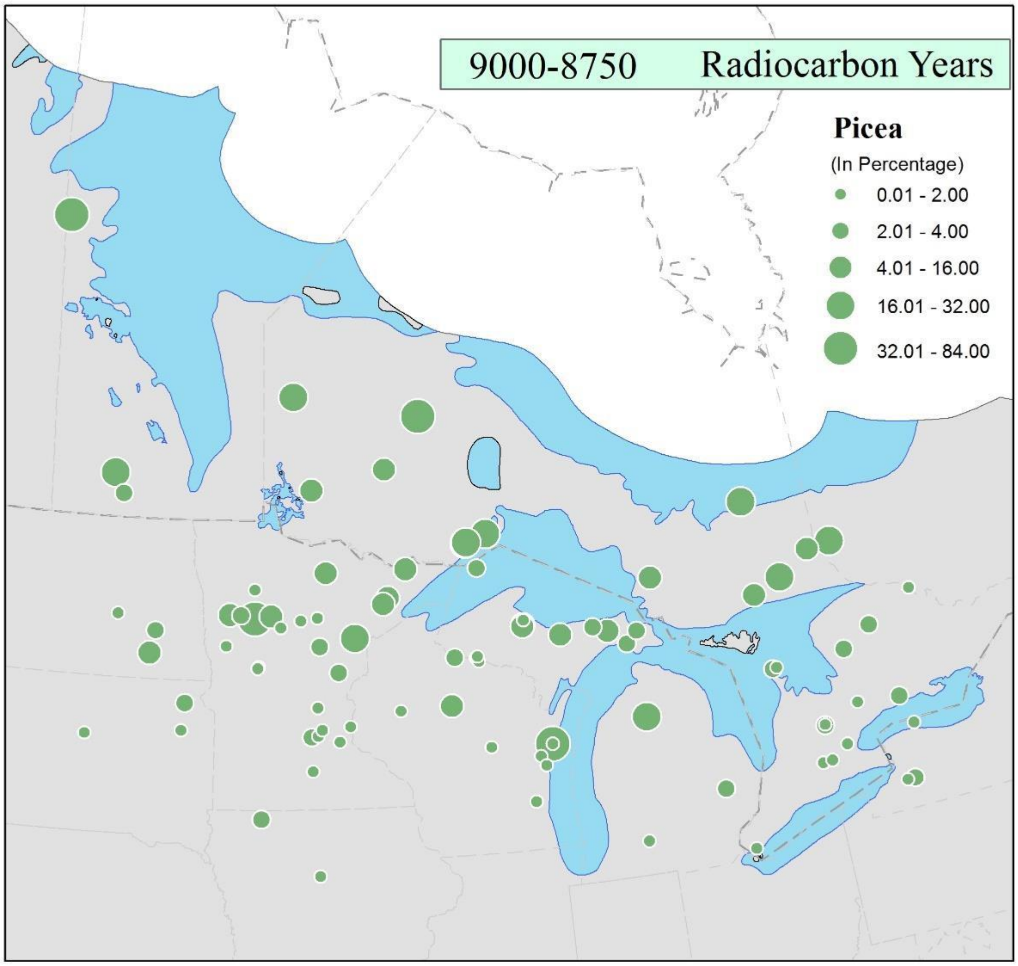
Appendix II

Pollen abundance of *Picea*

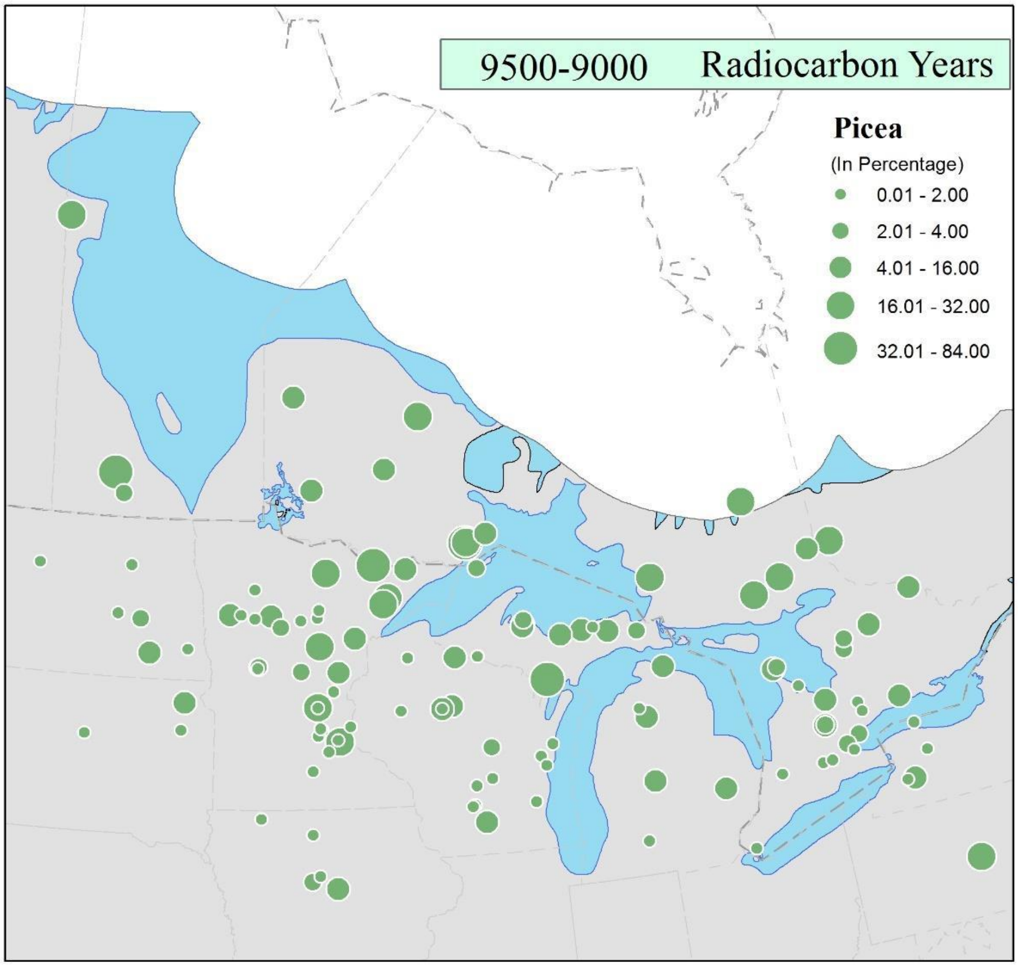

8250-8000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

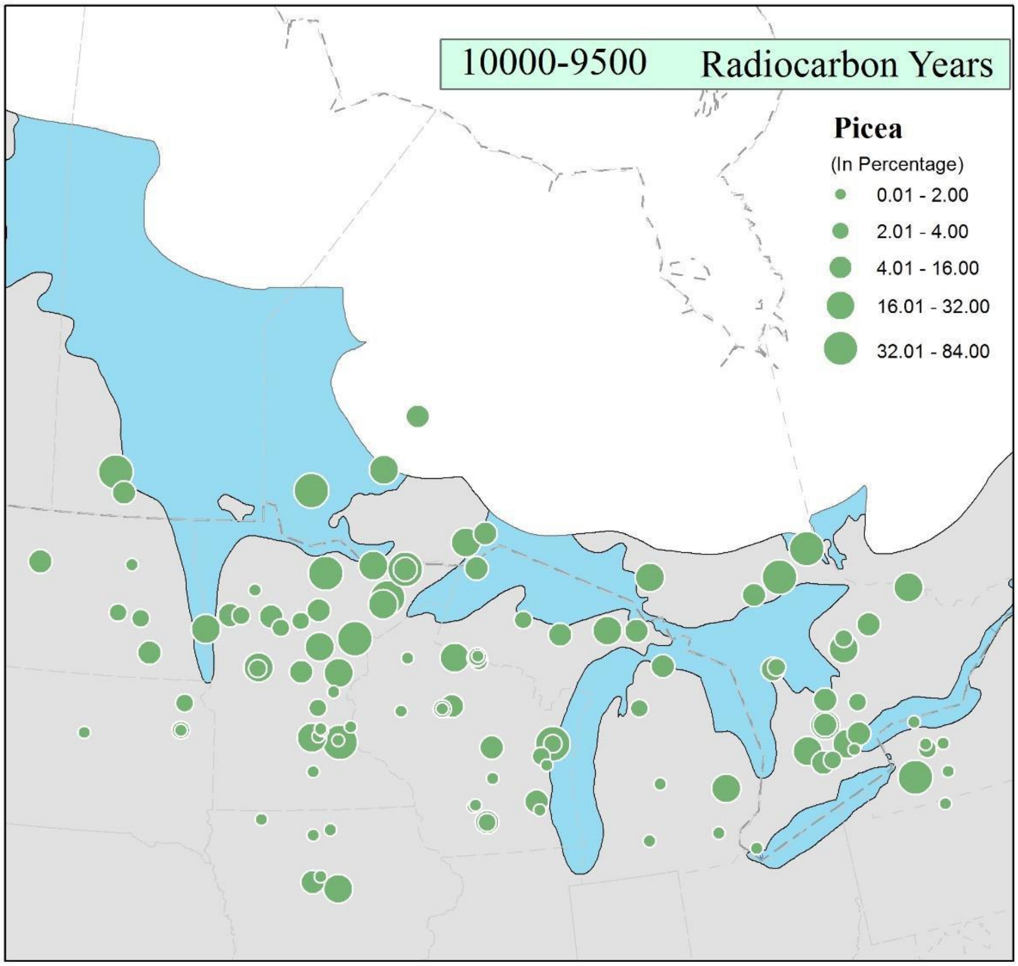

8500-8250 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

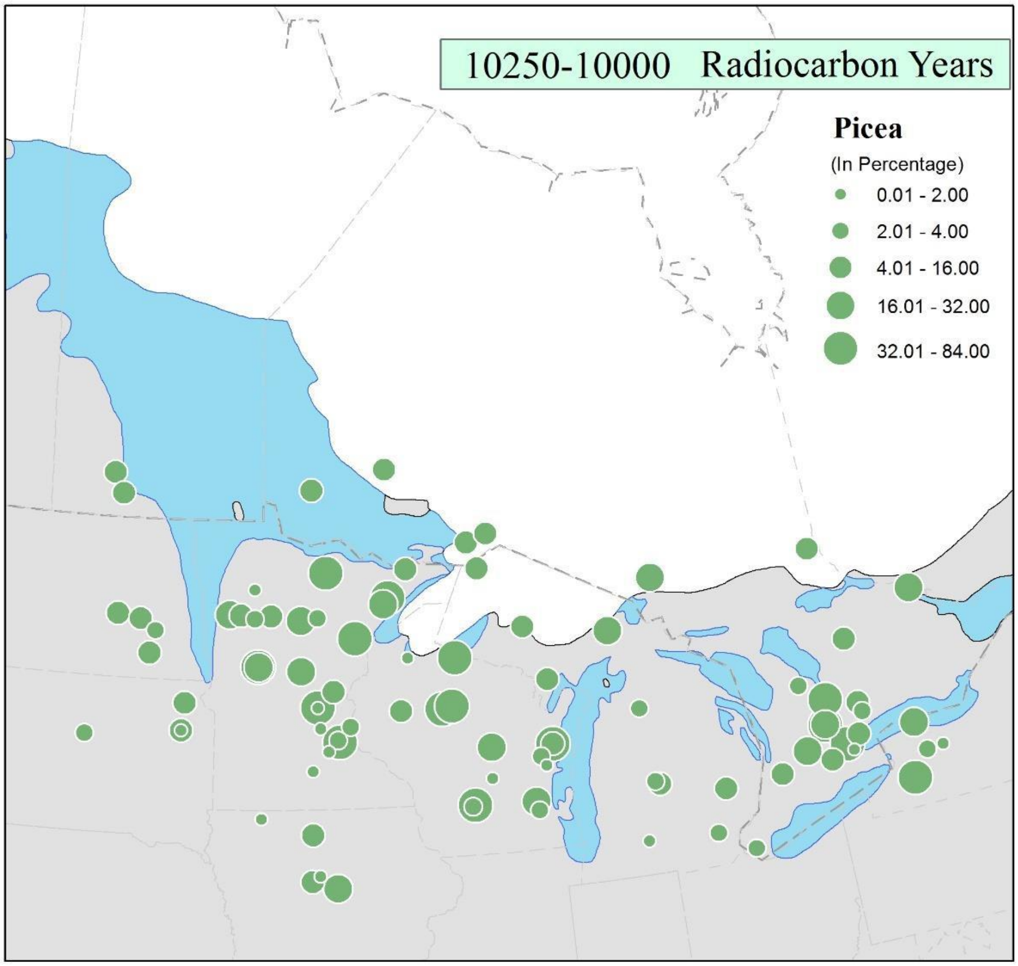

8750-8500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

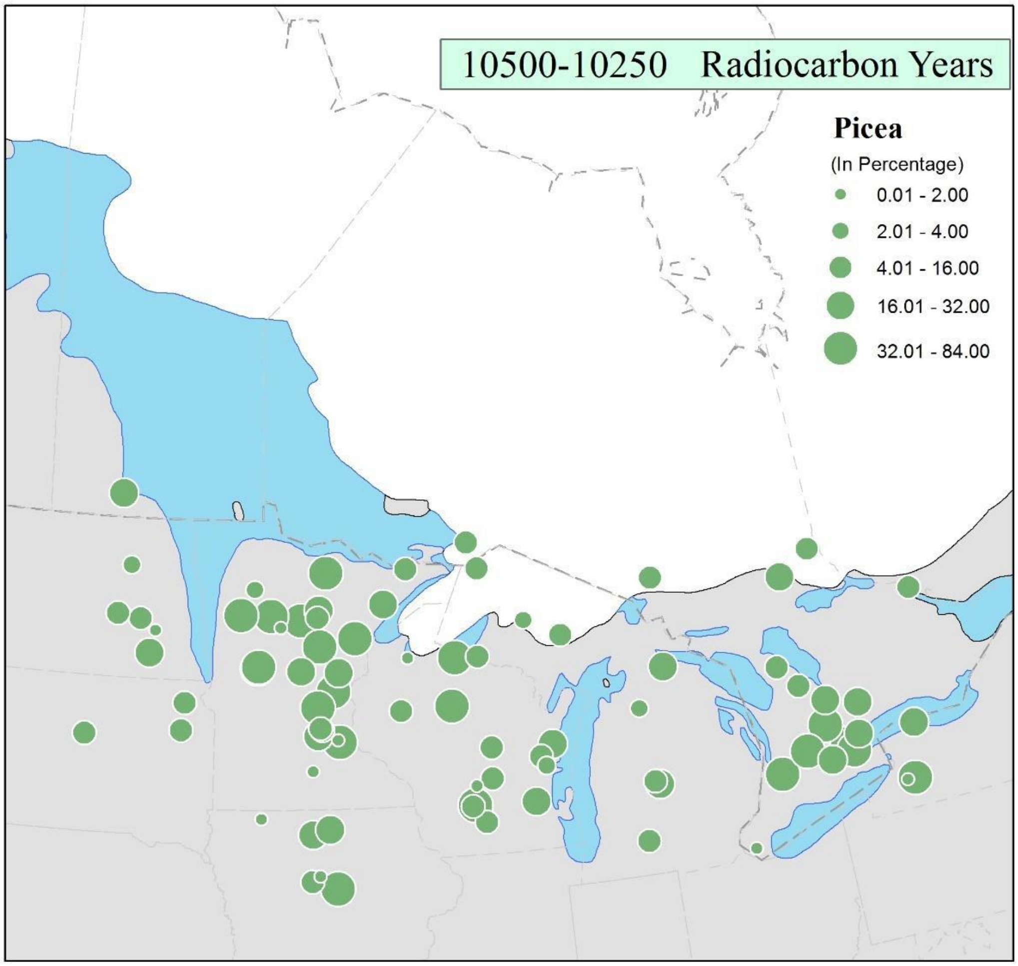


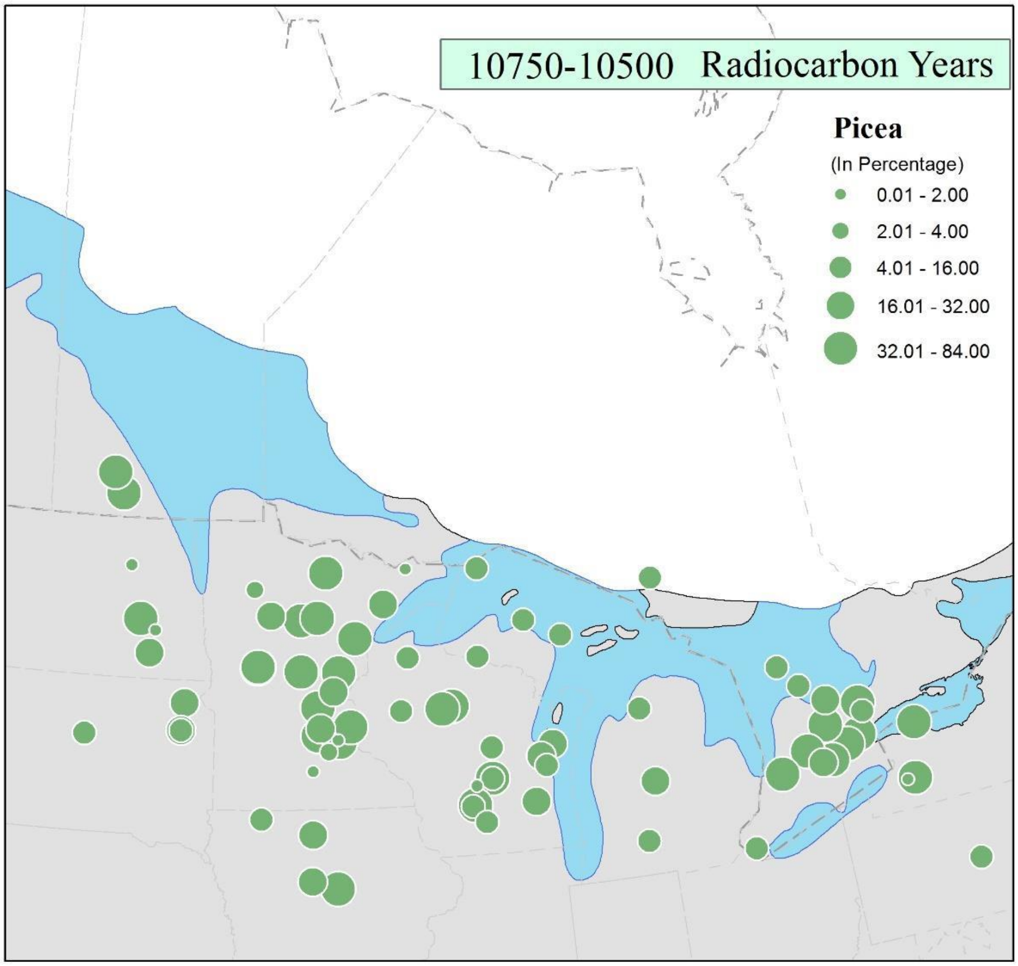
9000-8750 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

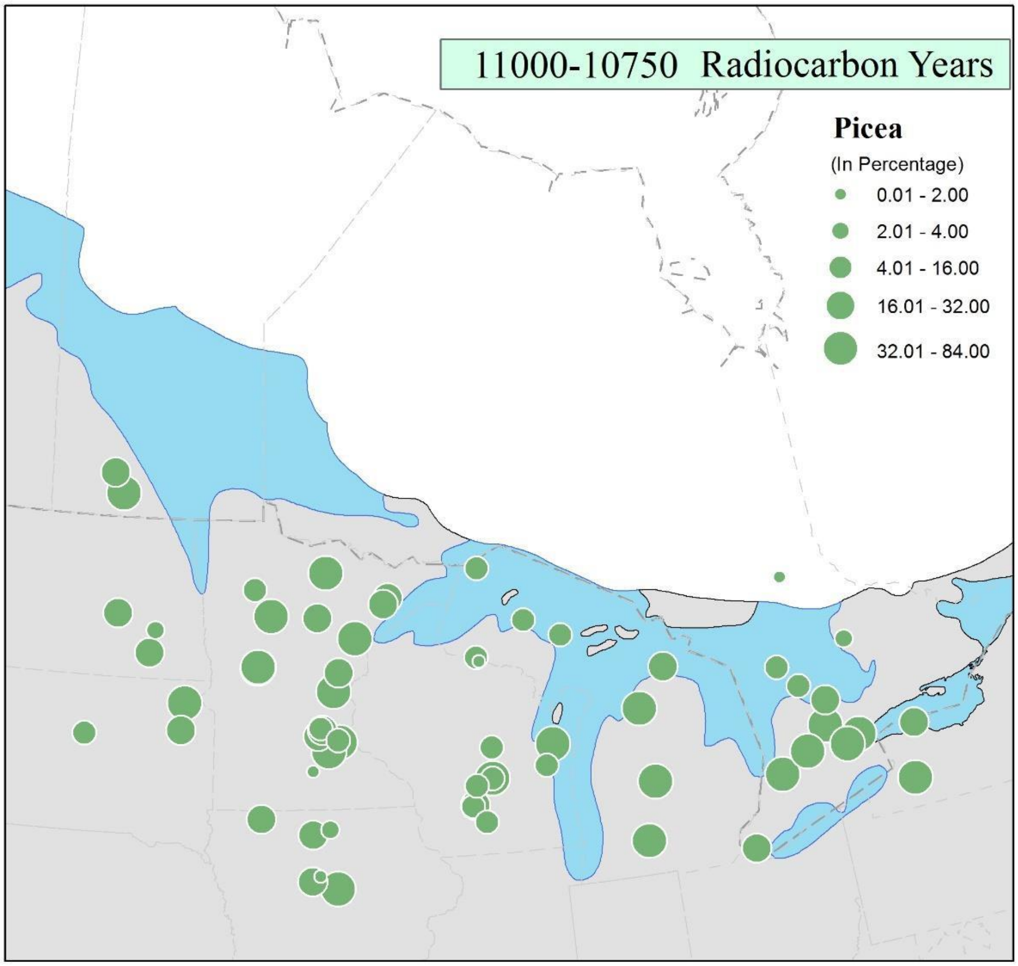

9500-9000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

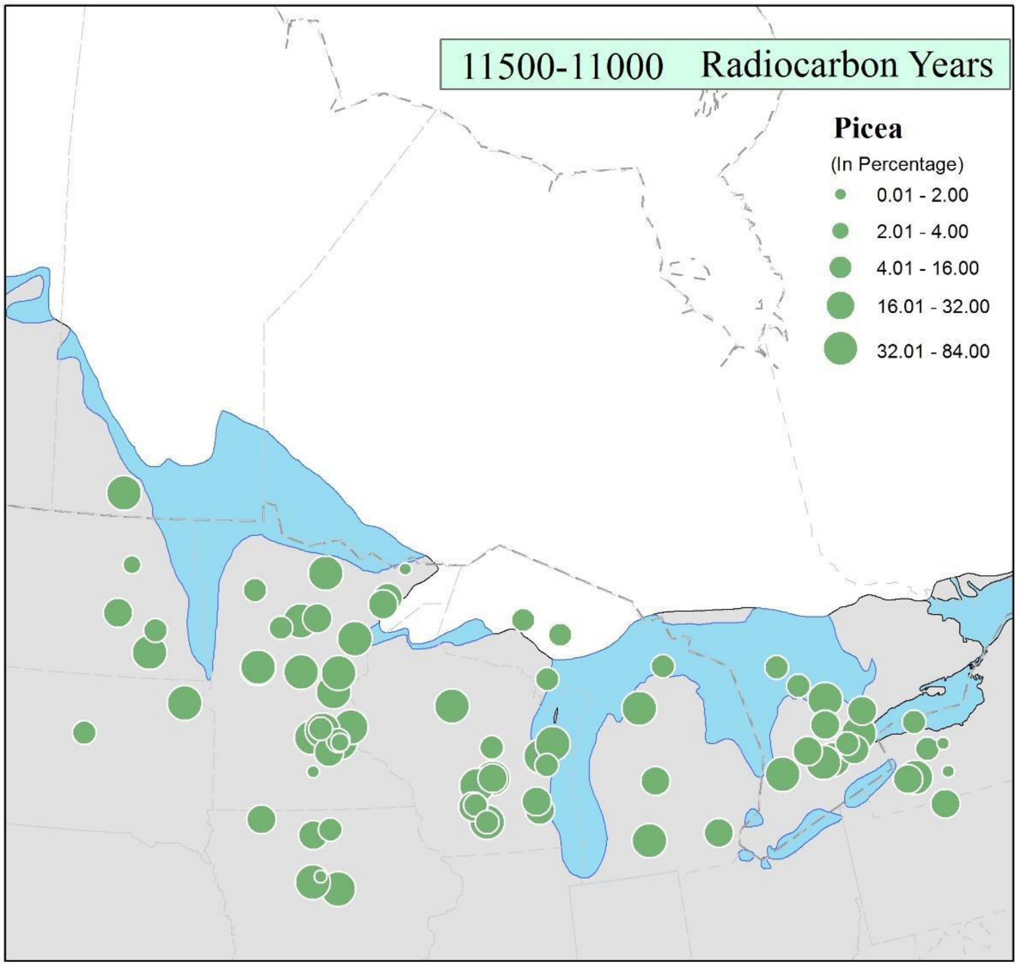

10000-9500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

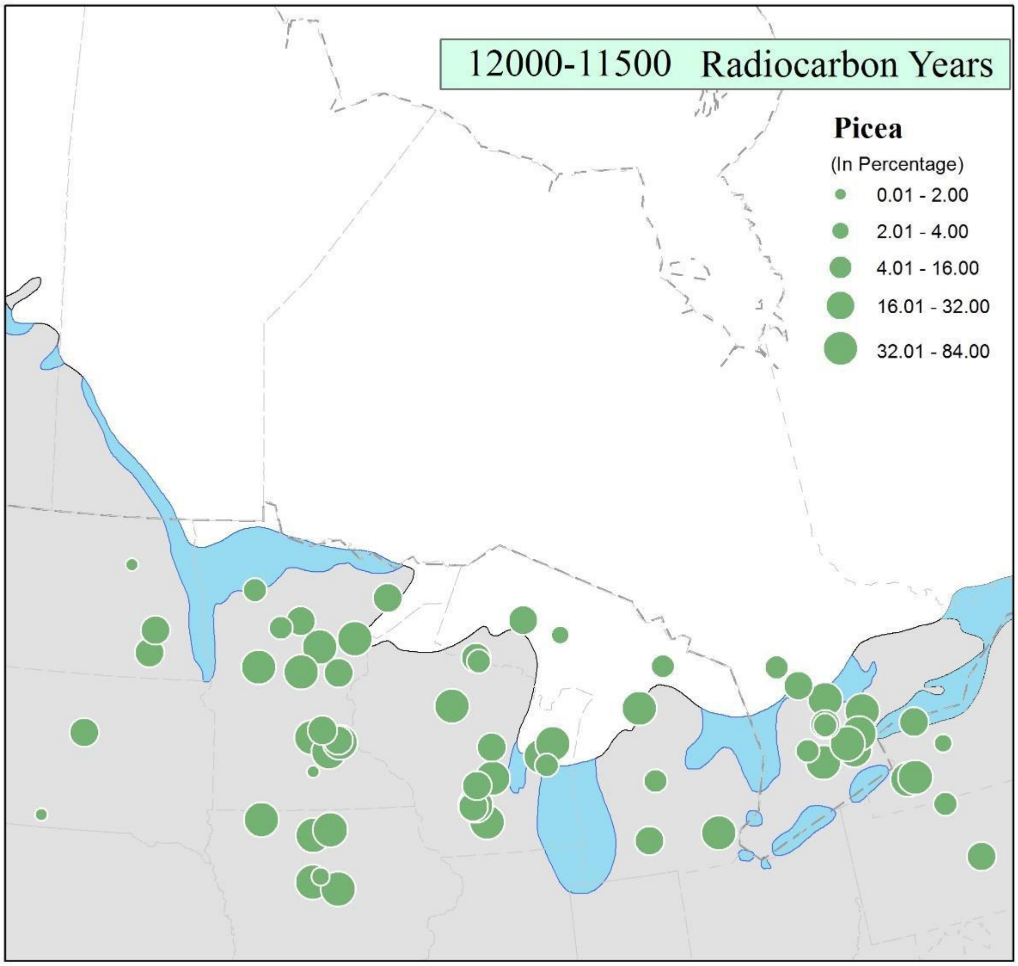

10250-10000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

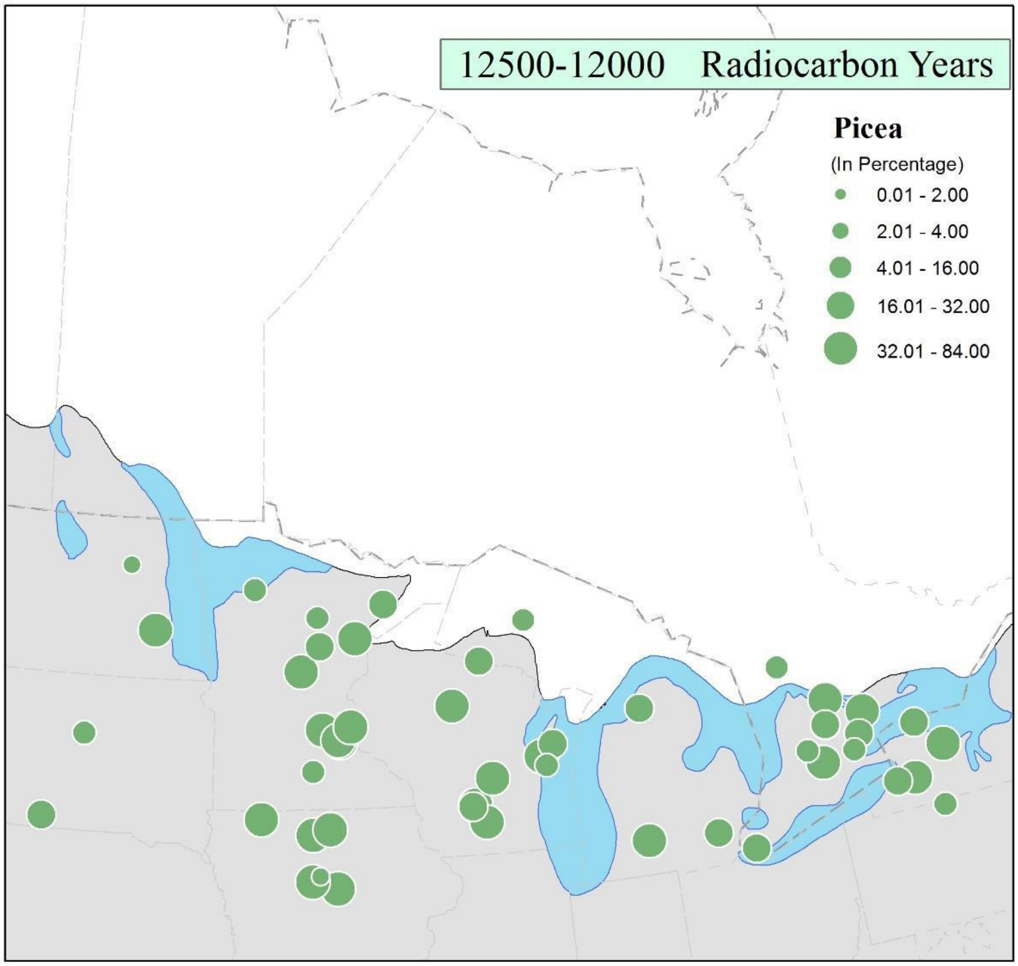

10500-10250 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

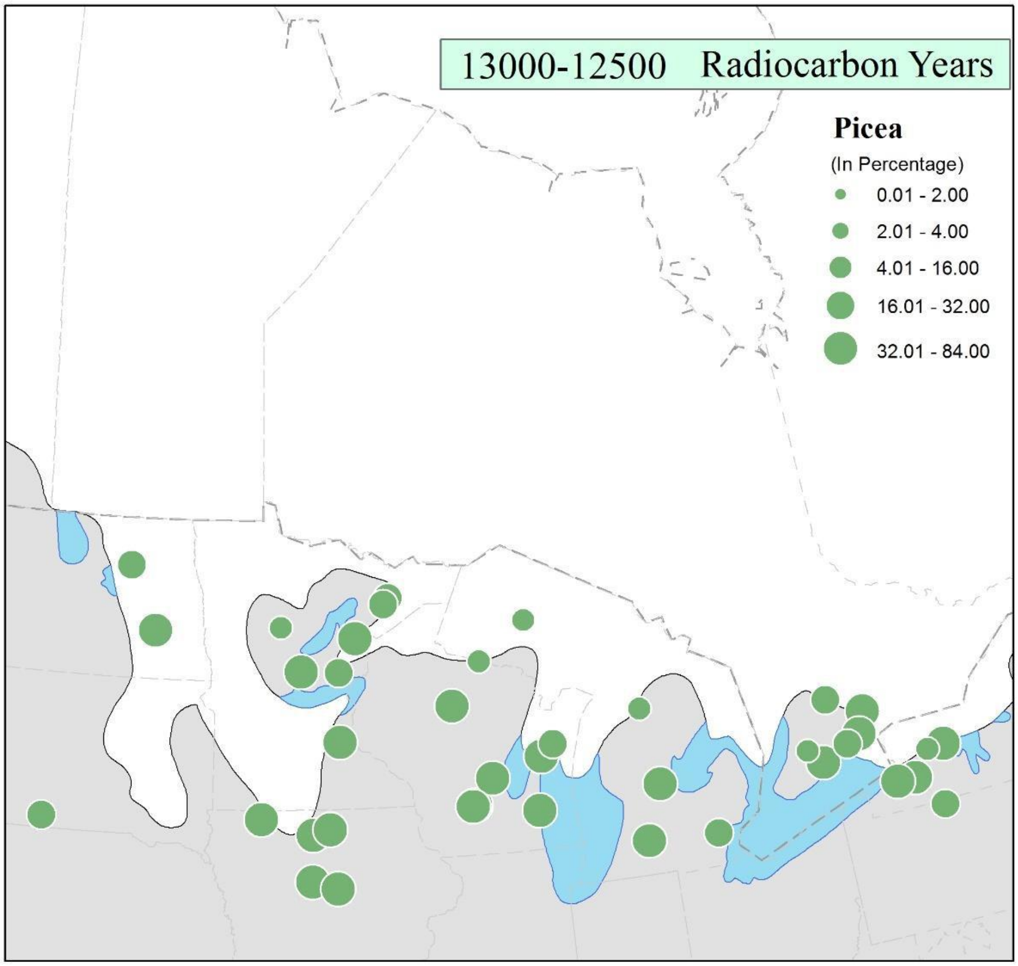

10750-10500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

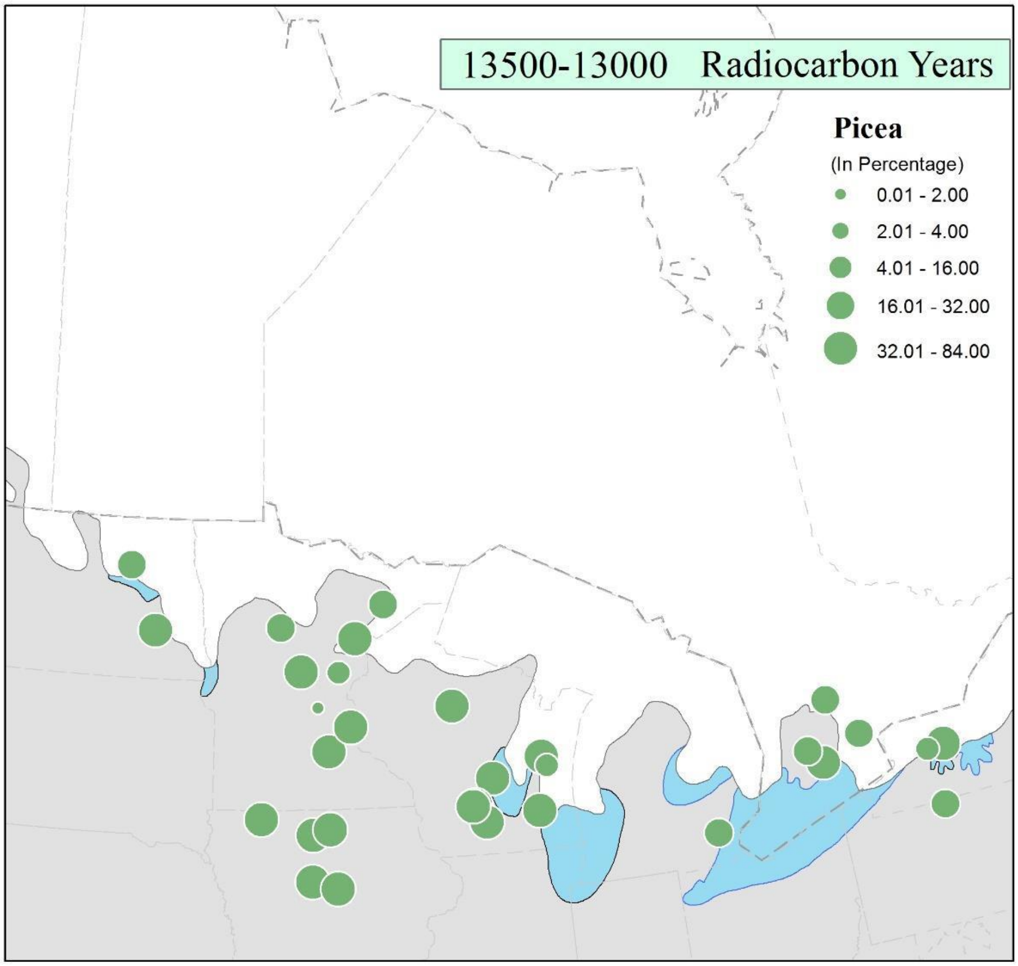

11000-10750 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

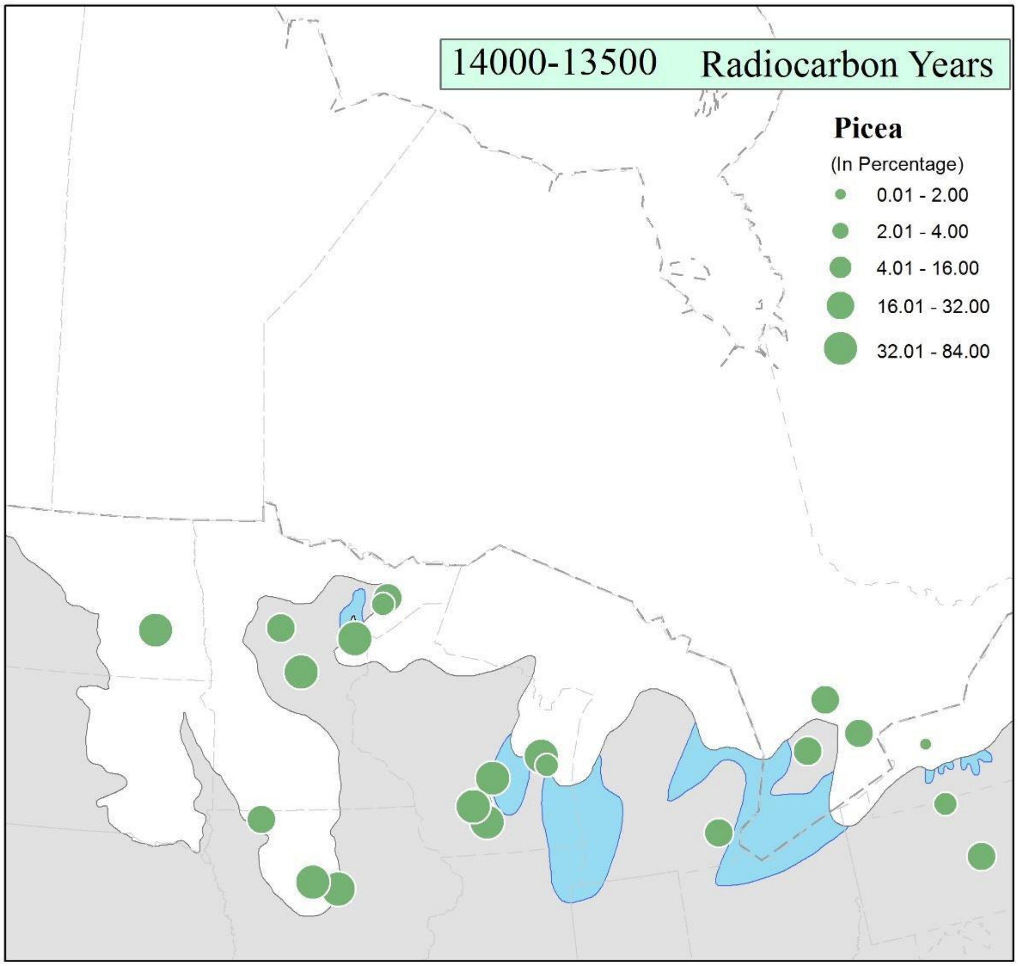

11500-11000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


12000-11500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

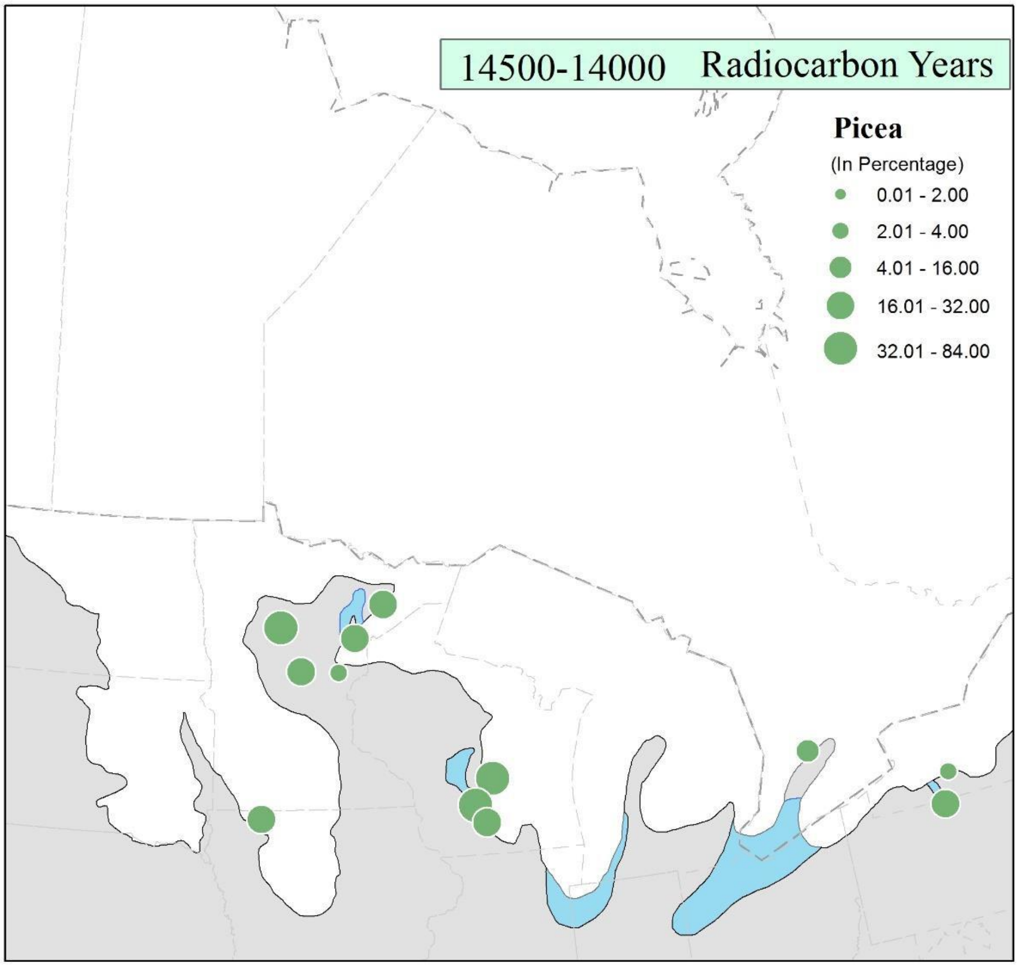

12500-12000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

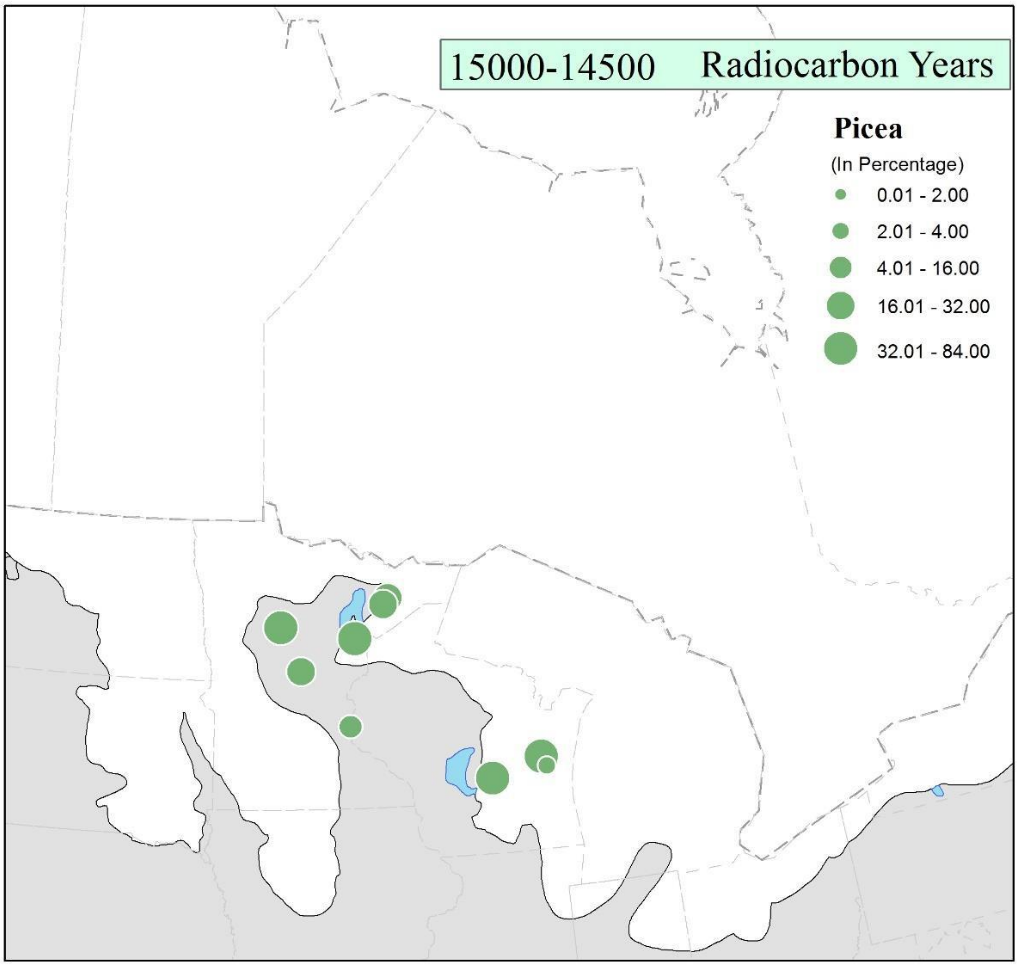

13000-12500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

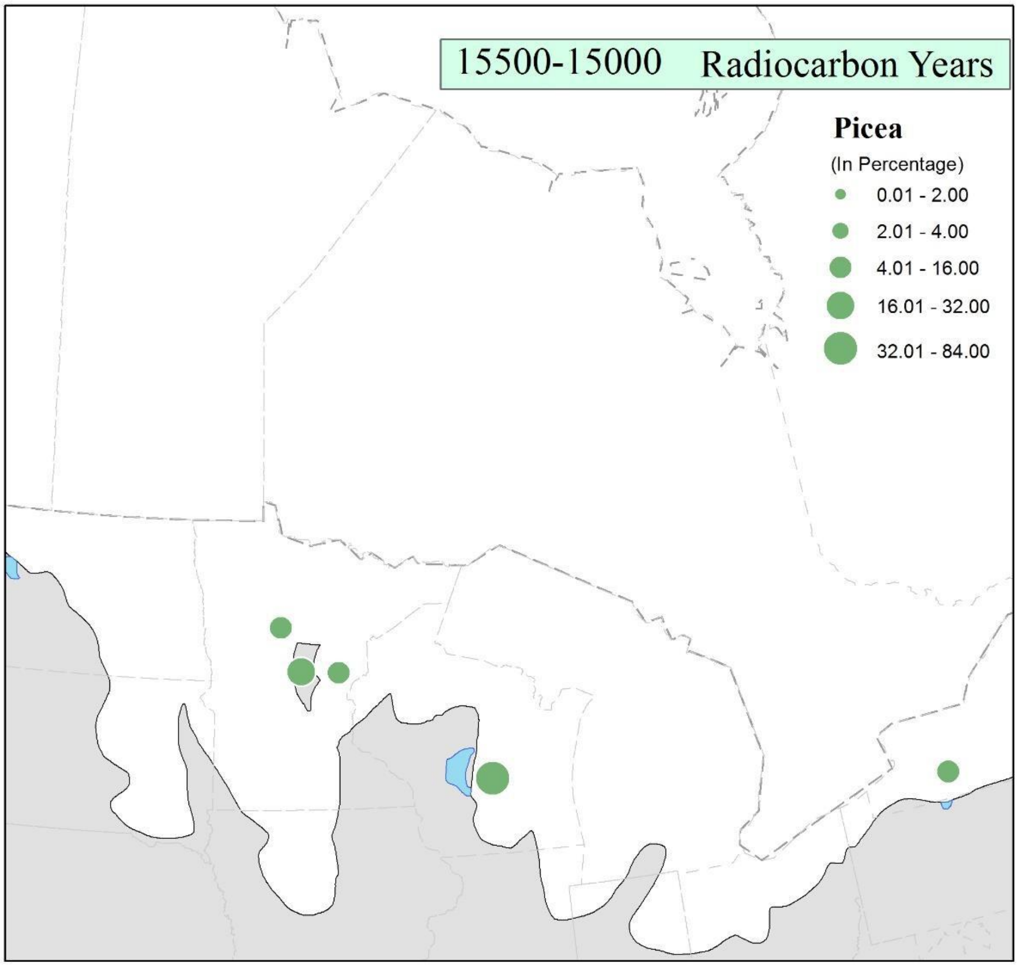

13500-13000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

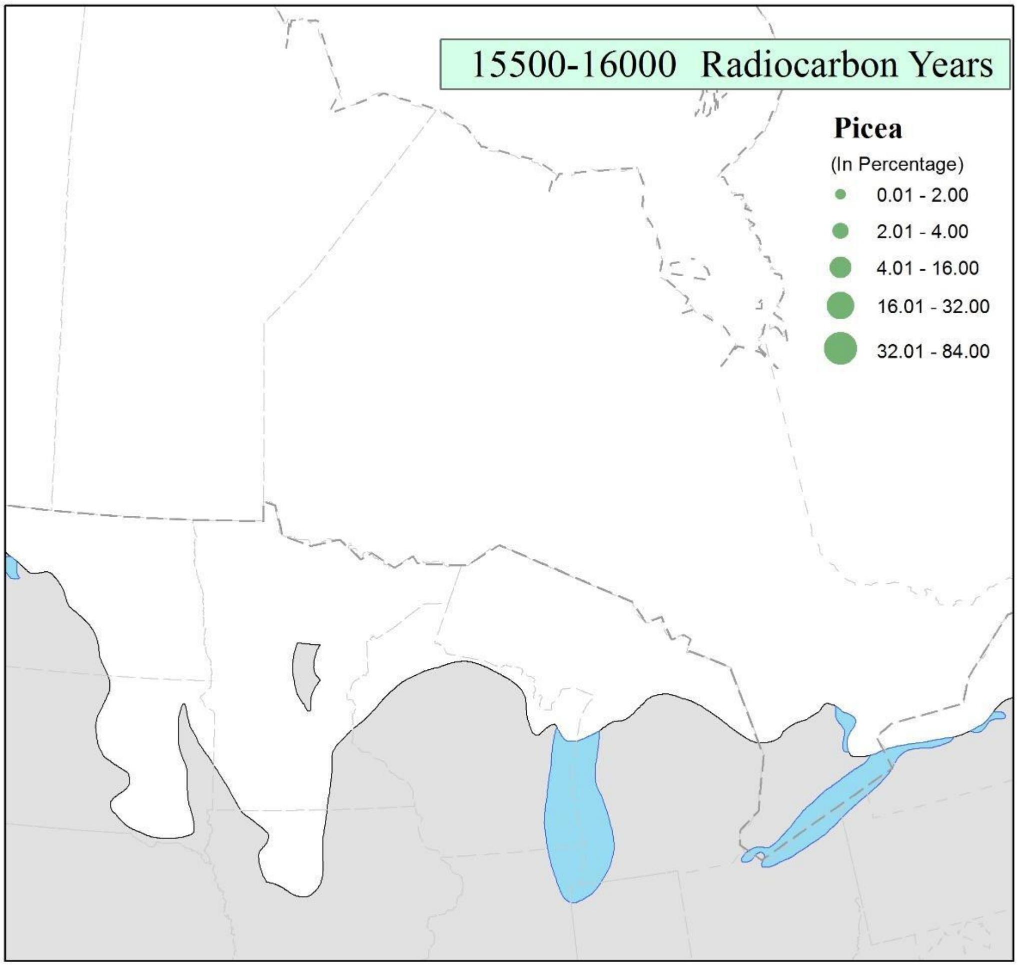


14000-13500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14500-14000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

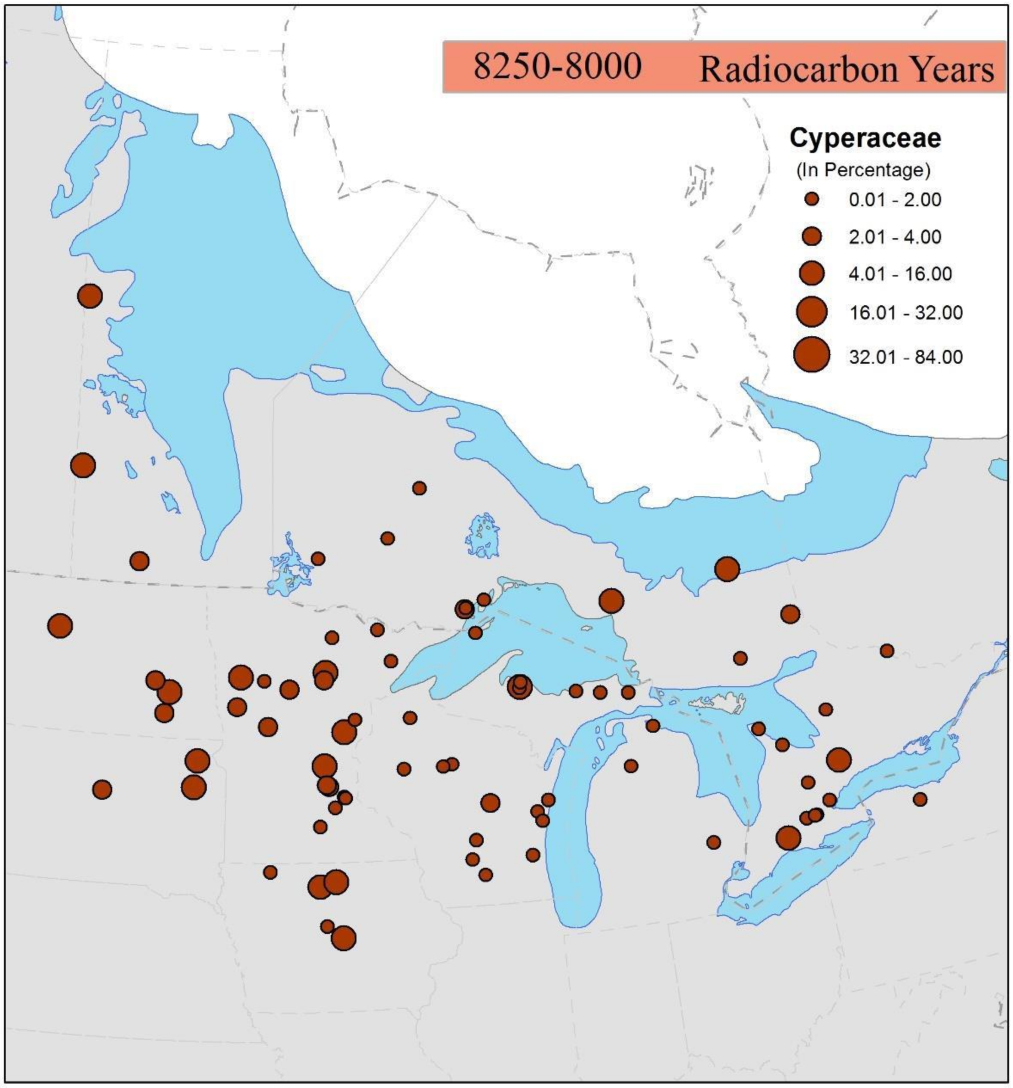

15000-14500 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

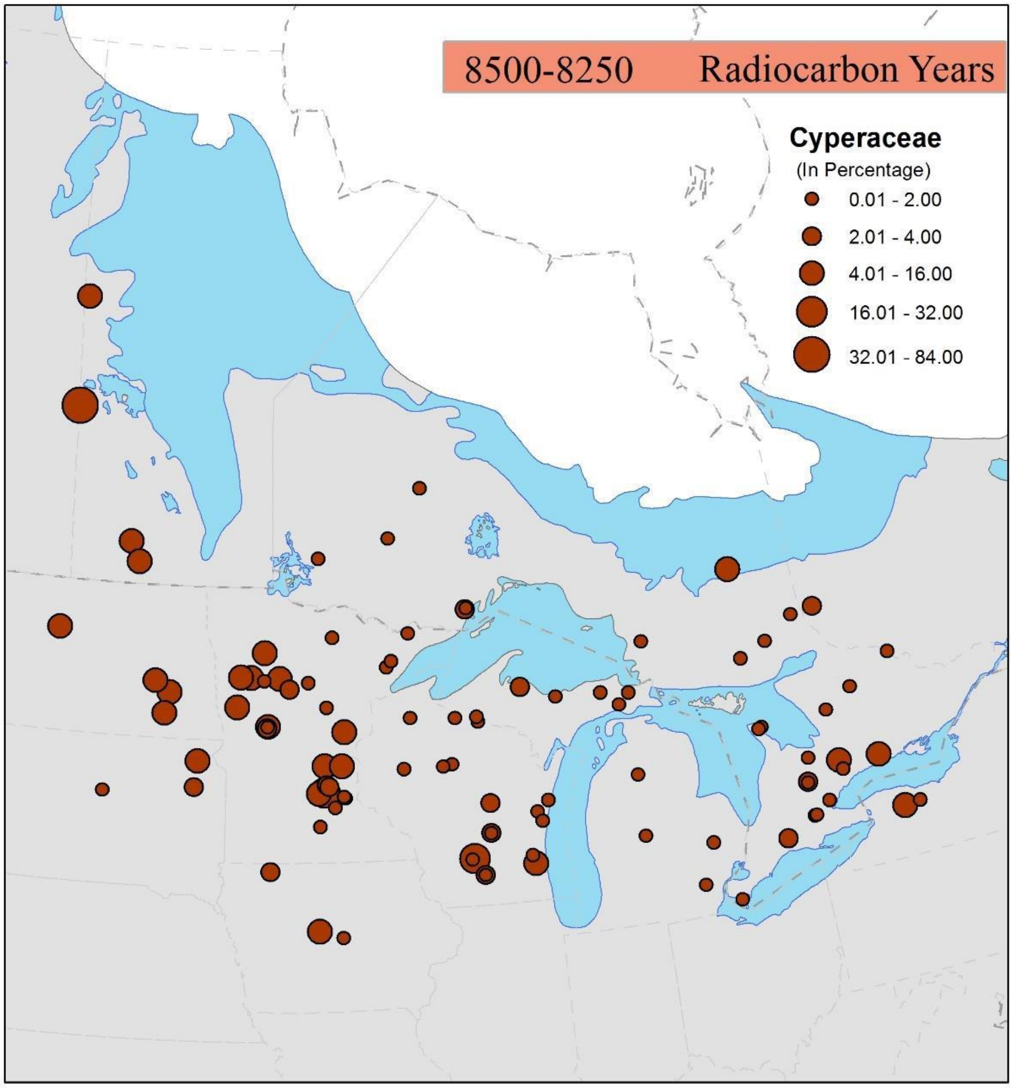

15500-15000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


15500-16000 Radiocarbon Years
Picea
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

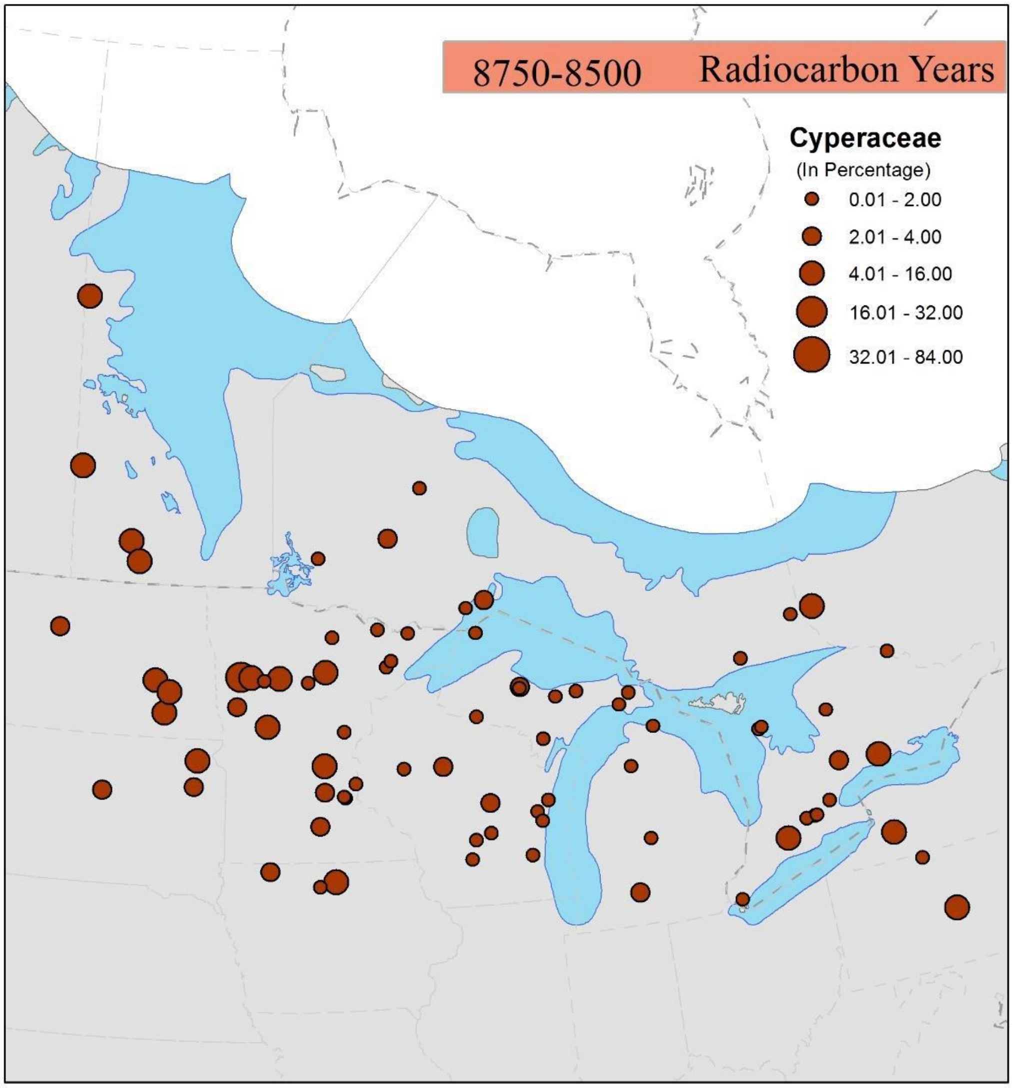
Appendix III

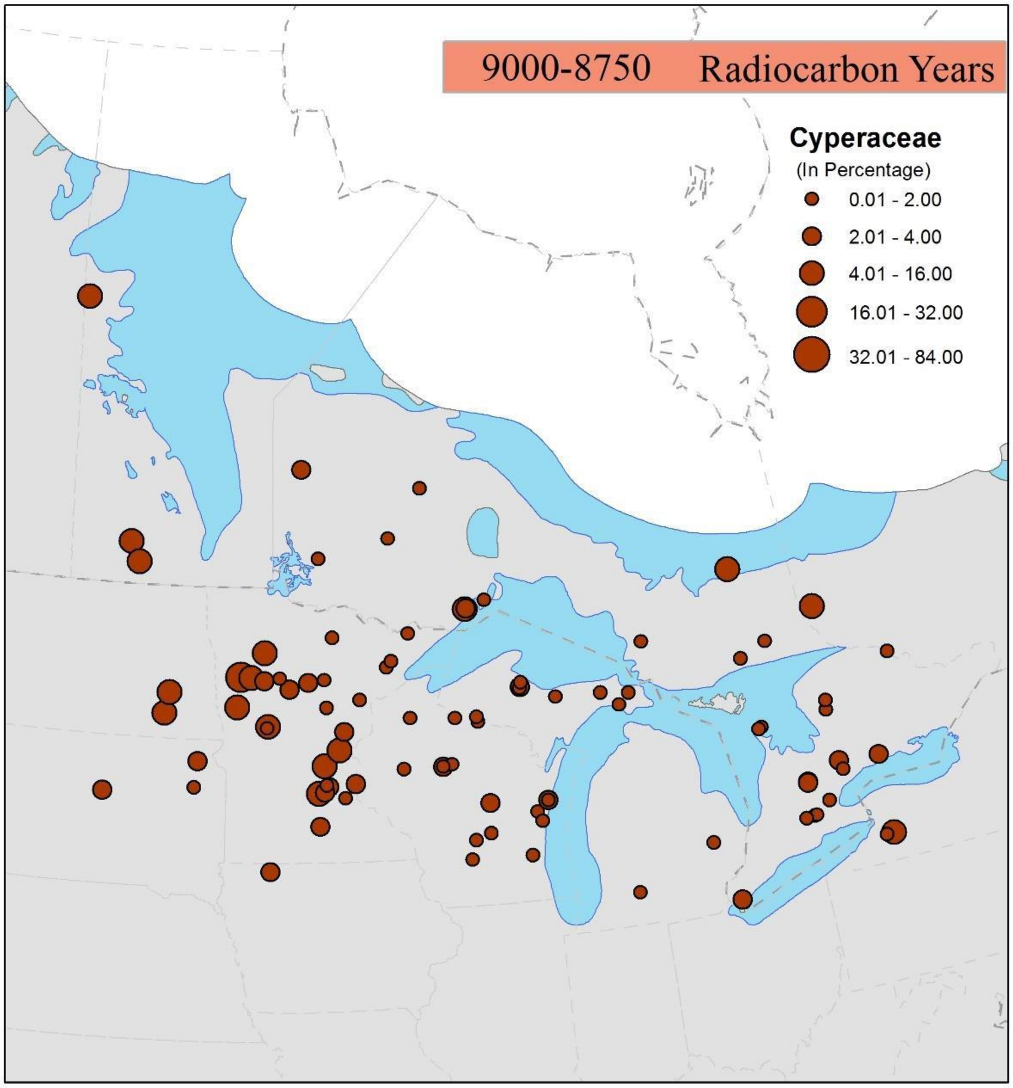
Pollen abundance of *Cyperaceae*

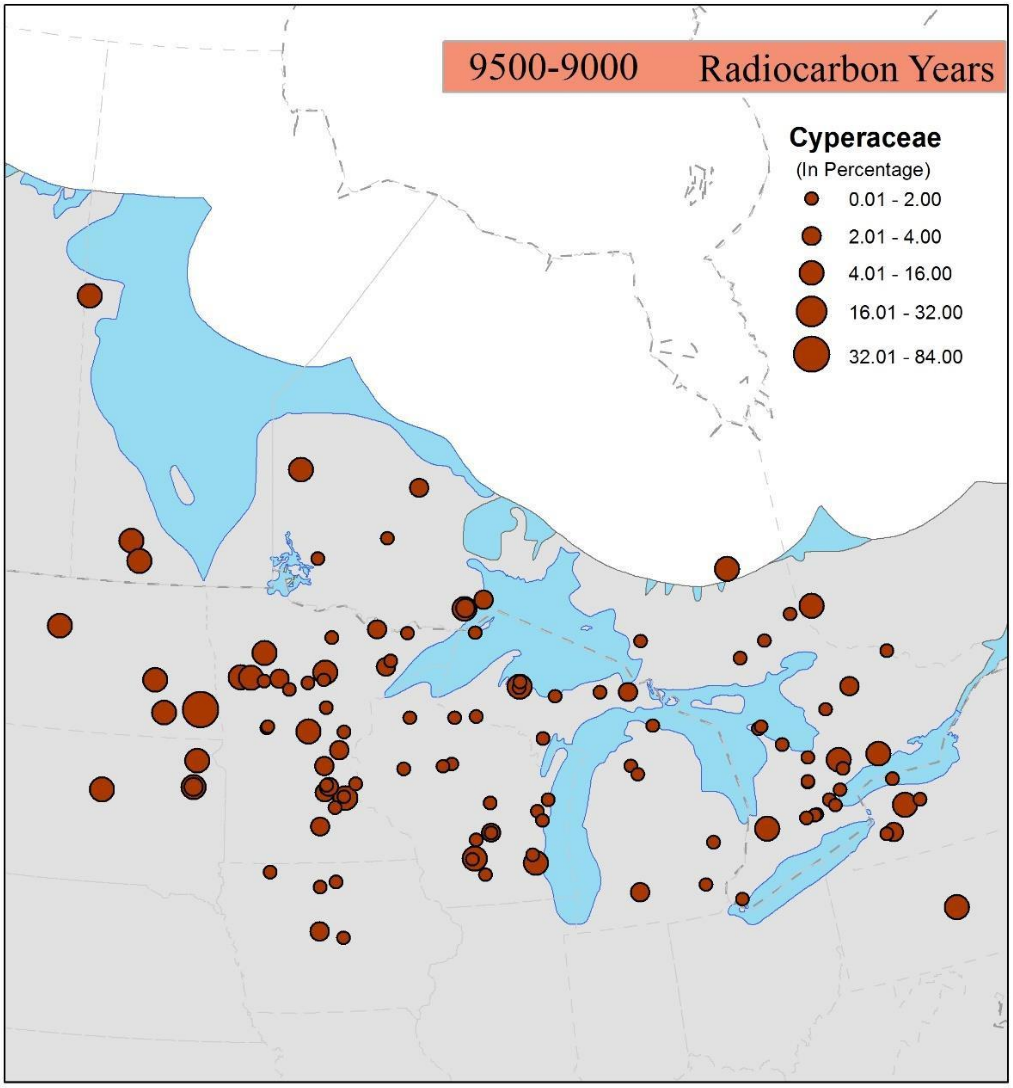

8250-8000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

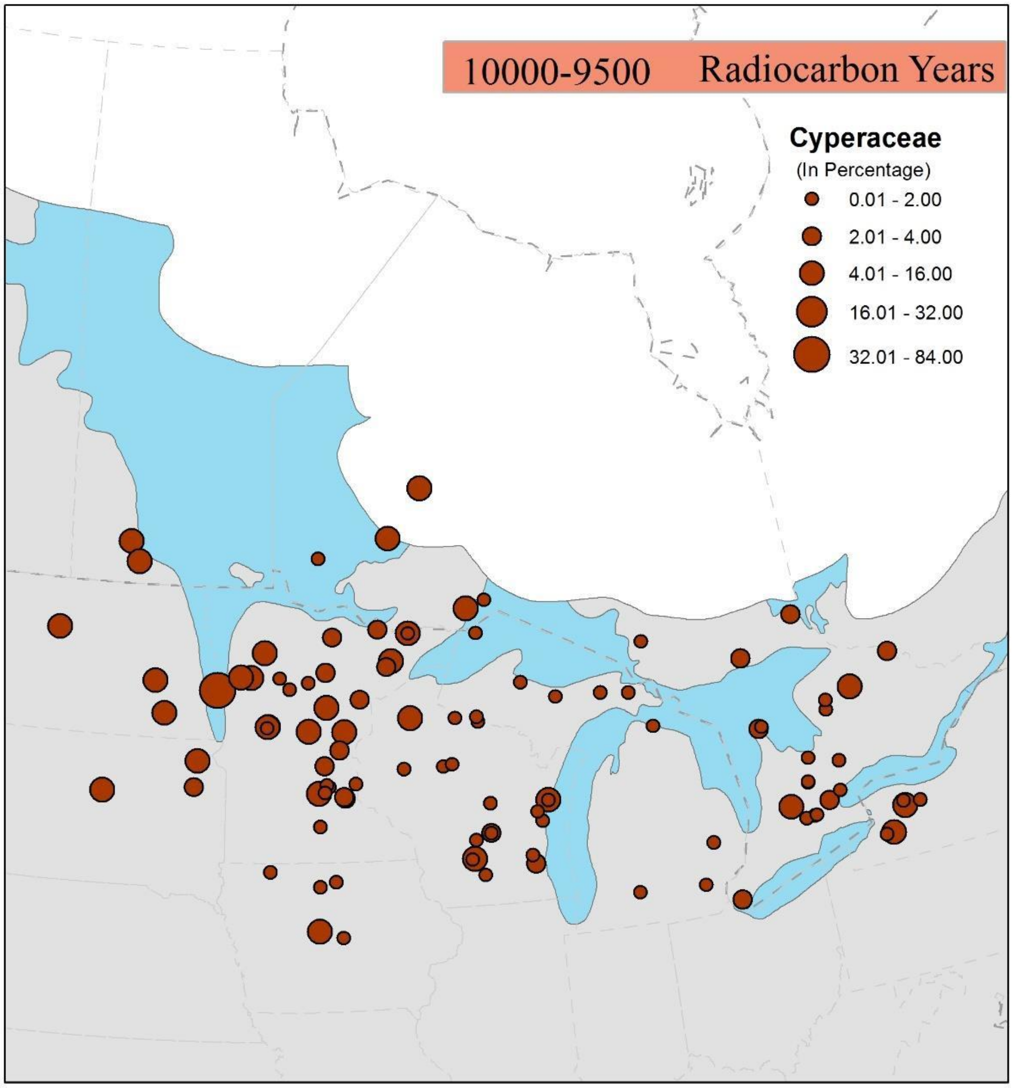


8500-8250 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

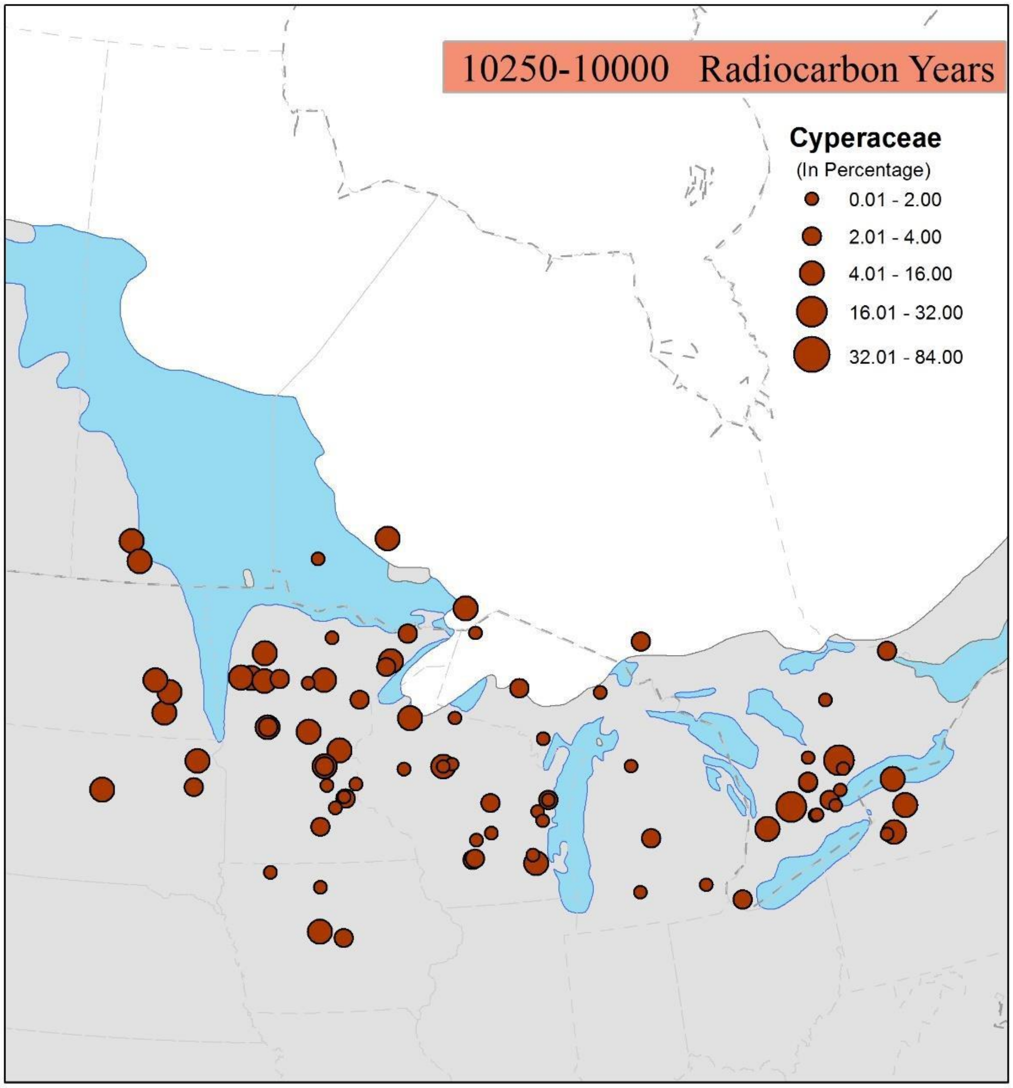

8750-8500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

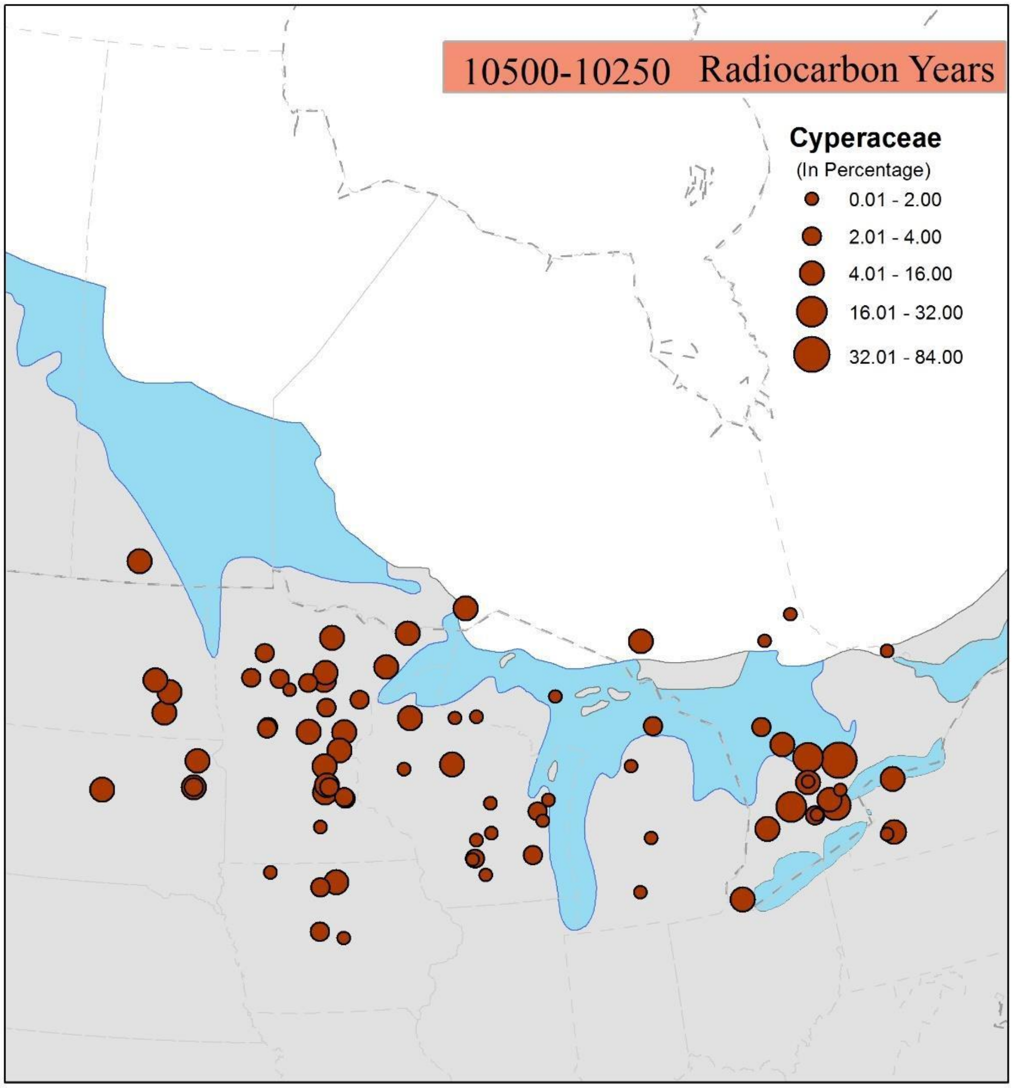

9000-8750 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

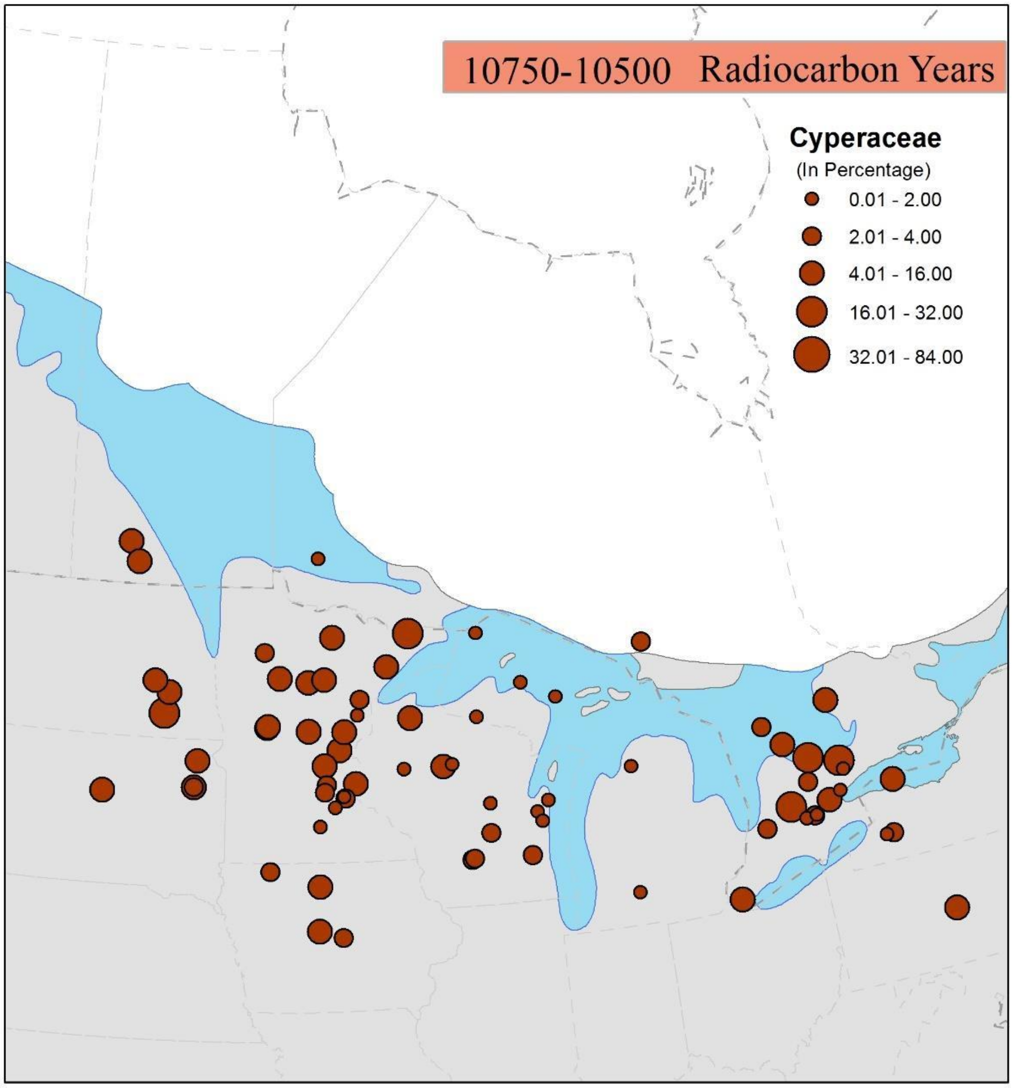

9500-9000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00



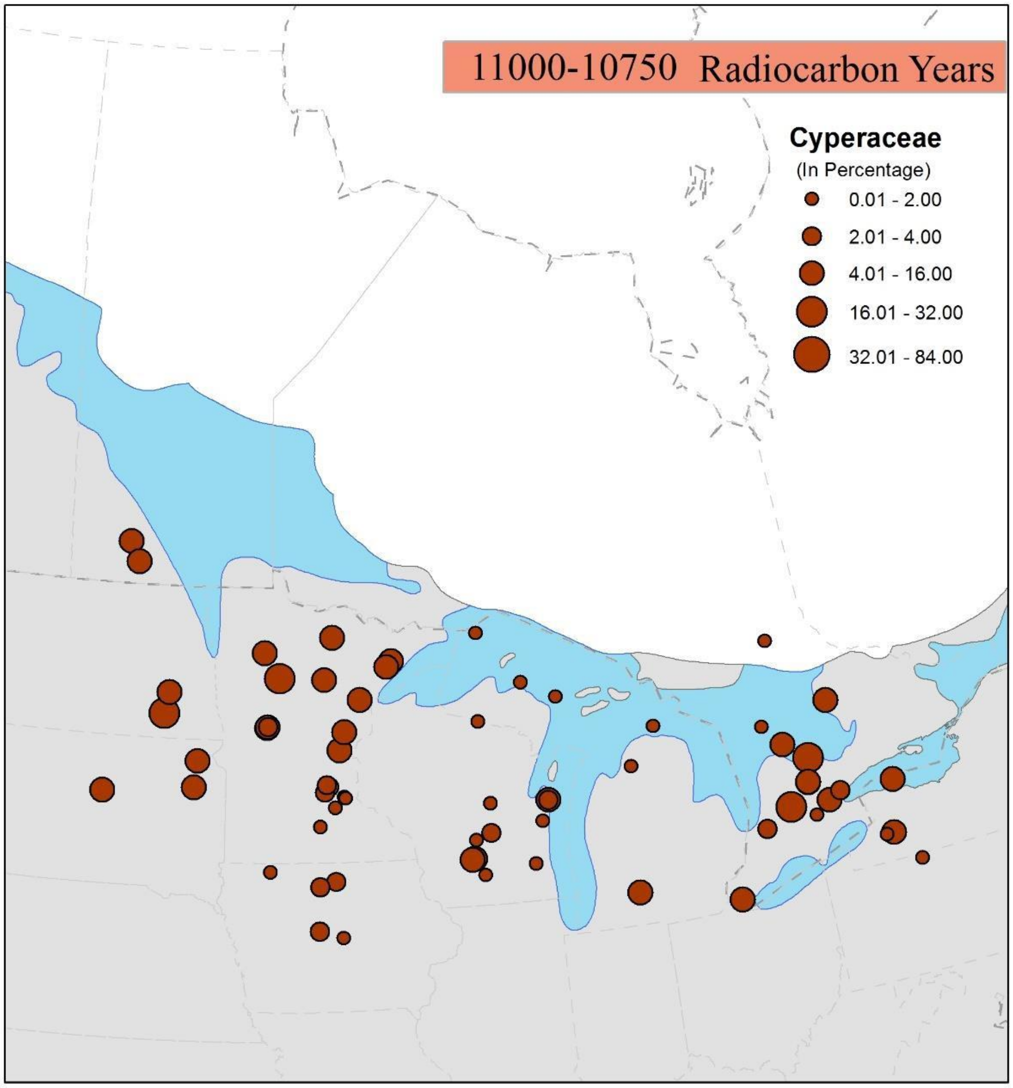
10000-9500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

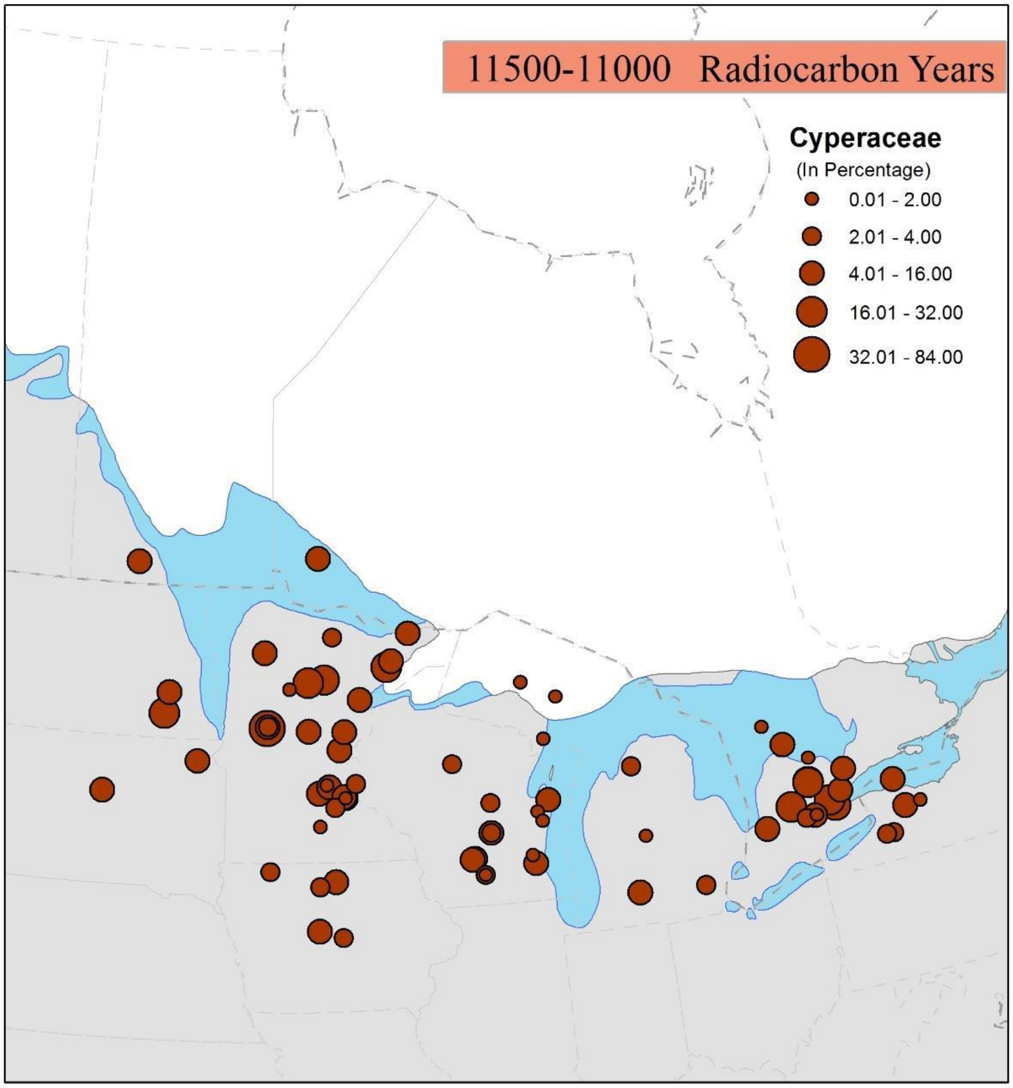

10250-10000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

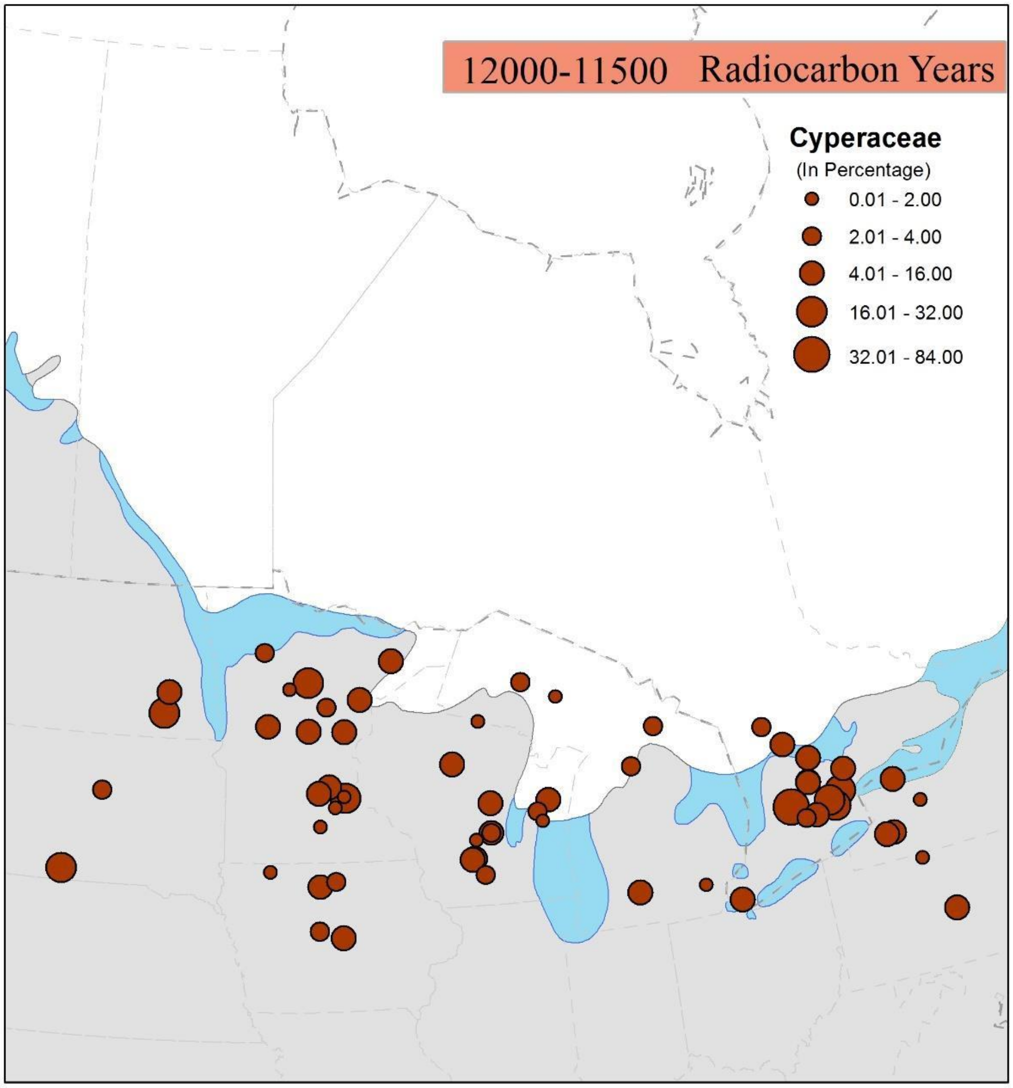

10500-10250 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

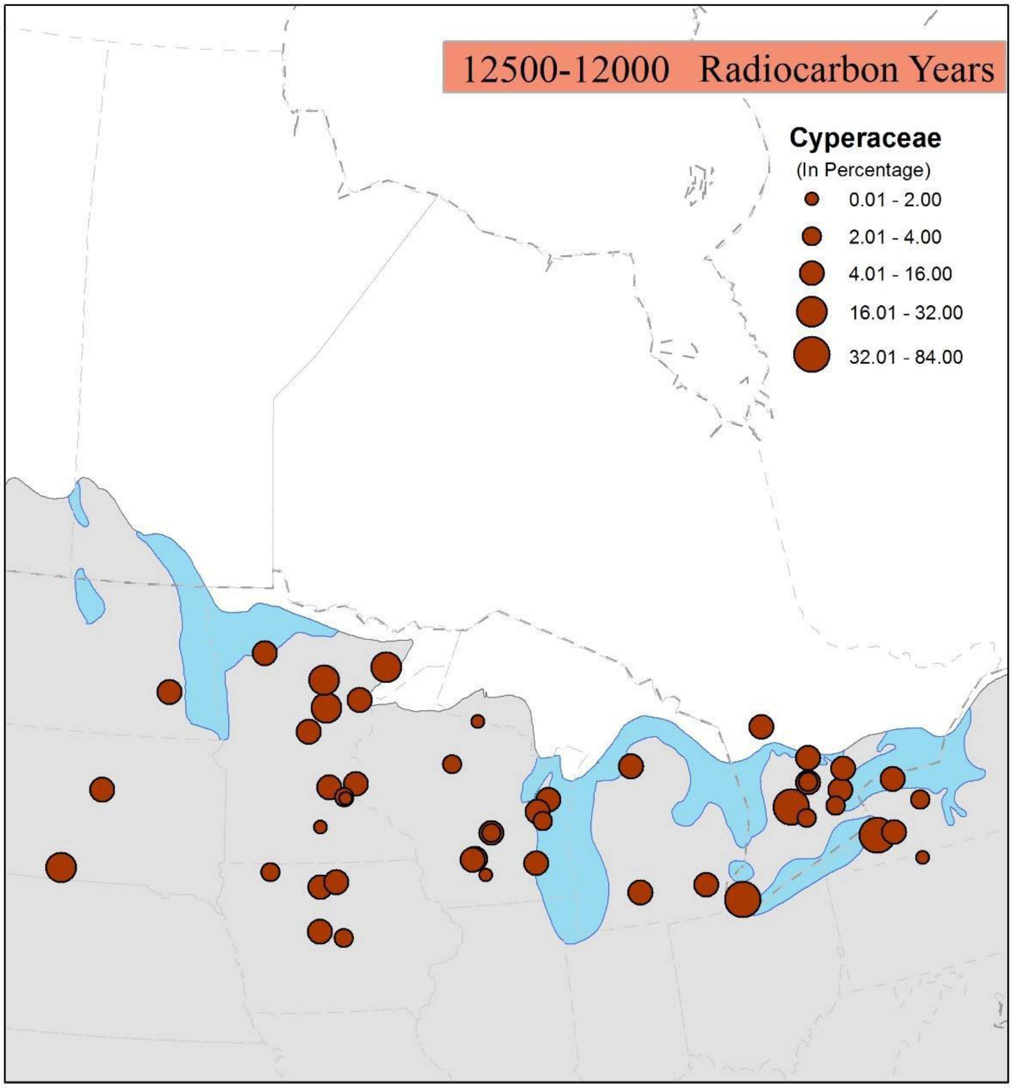


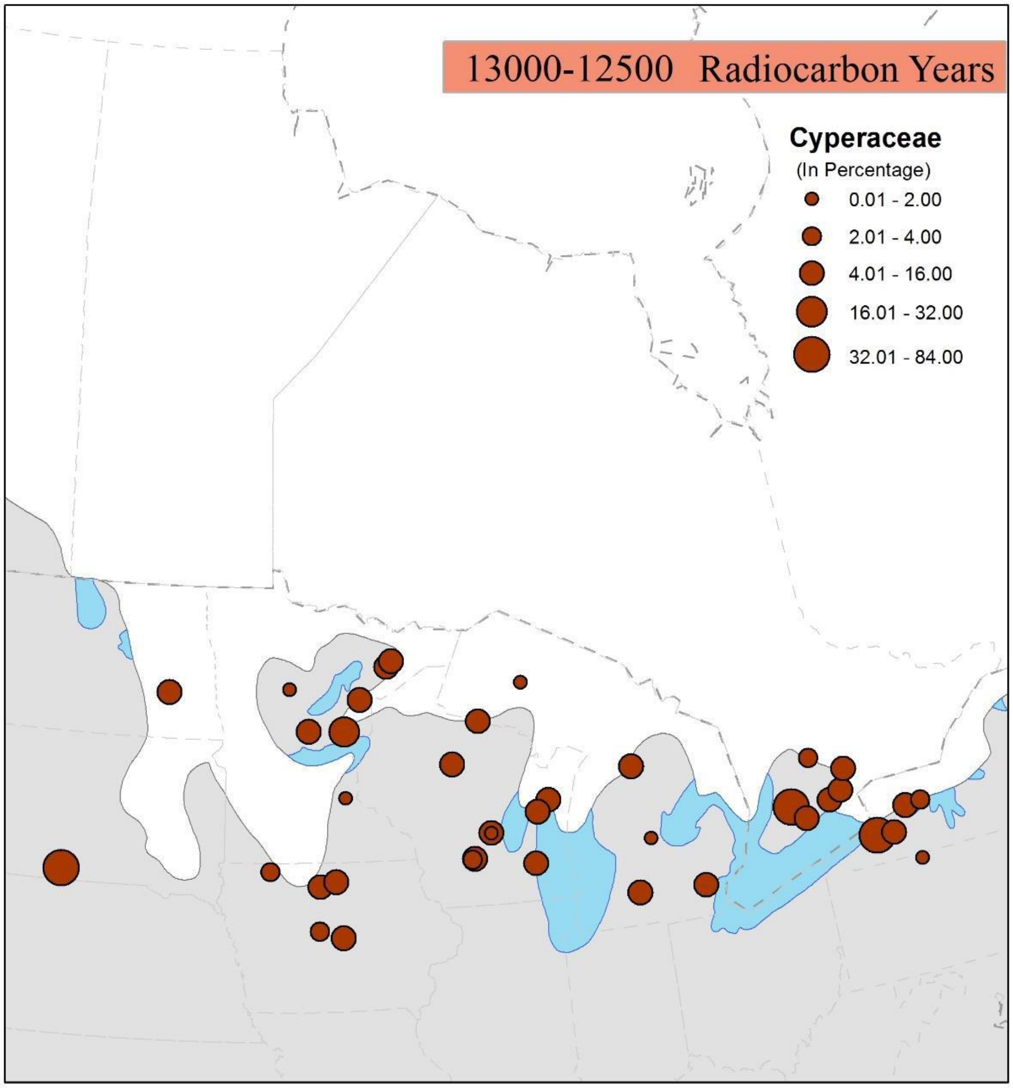
10750-10500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

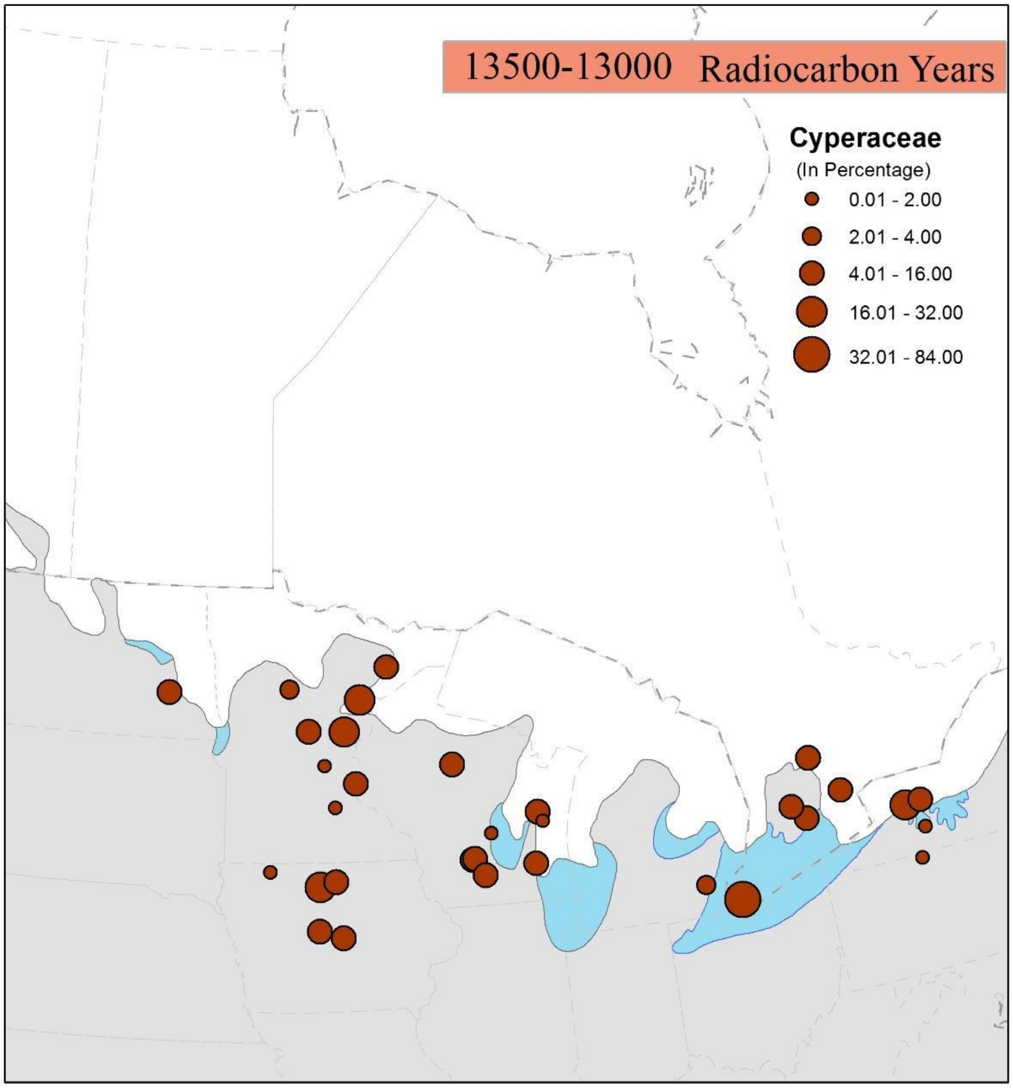

11000-10750 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

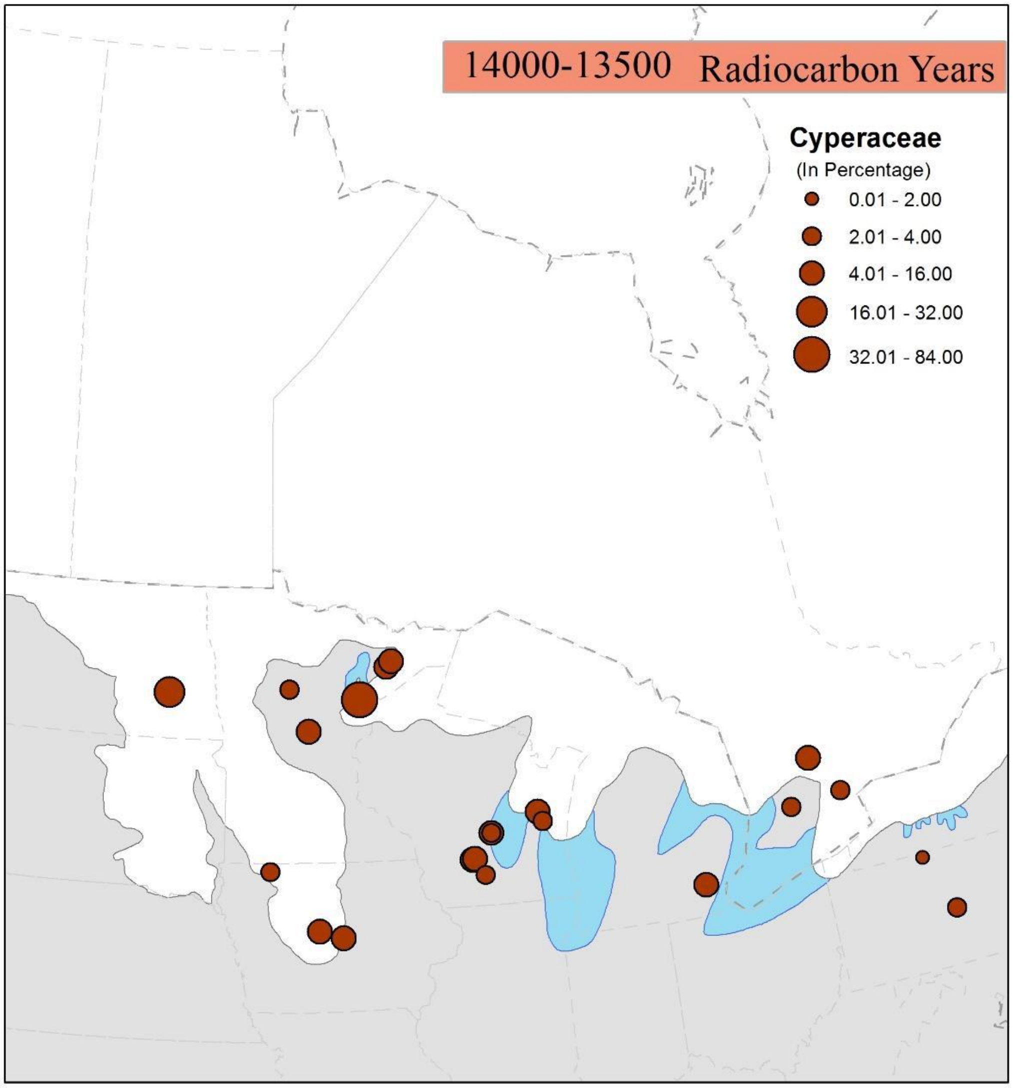

11500-11000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

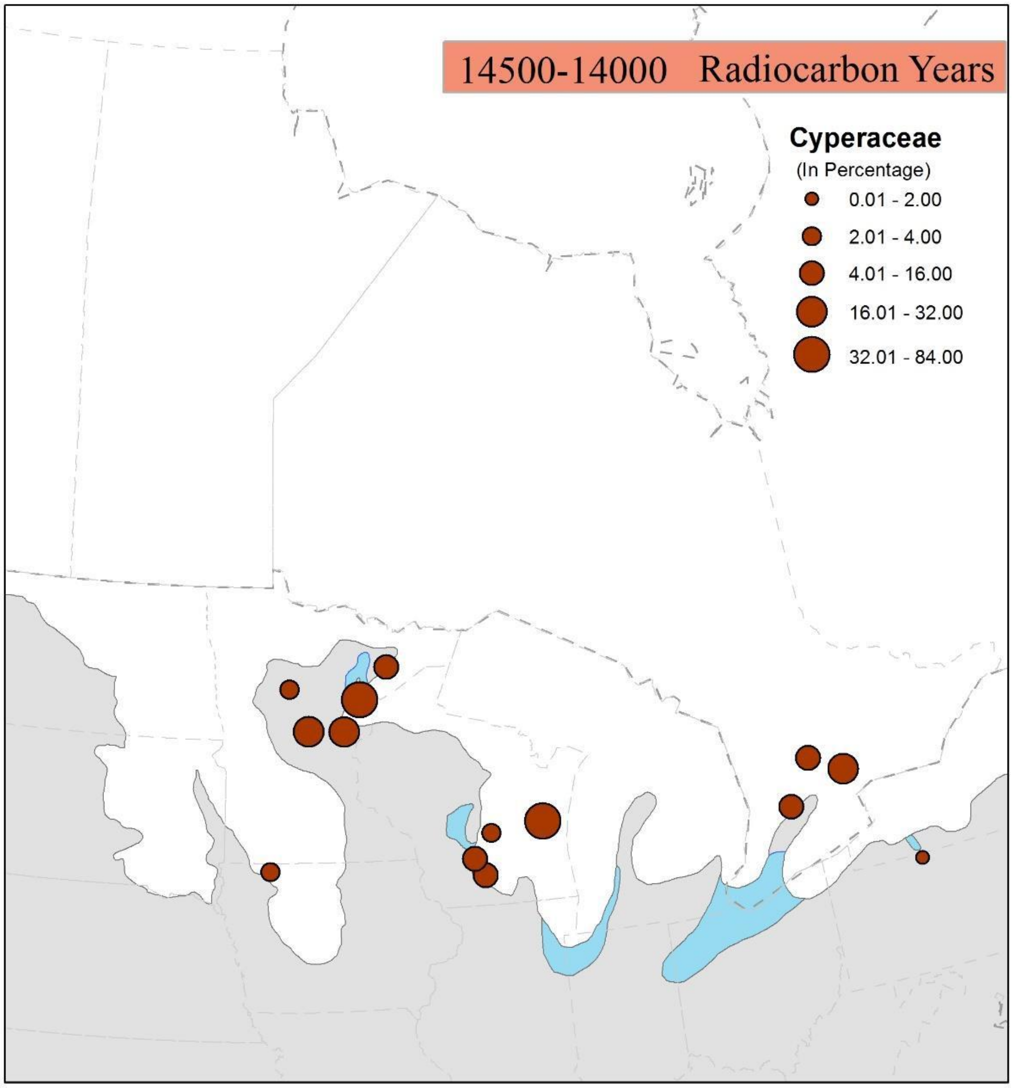

12000-11500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

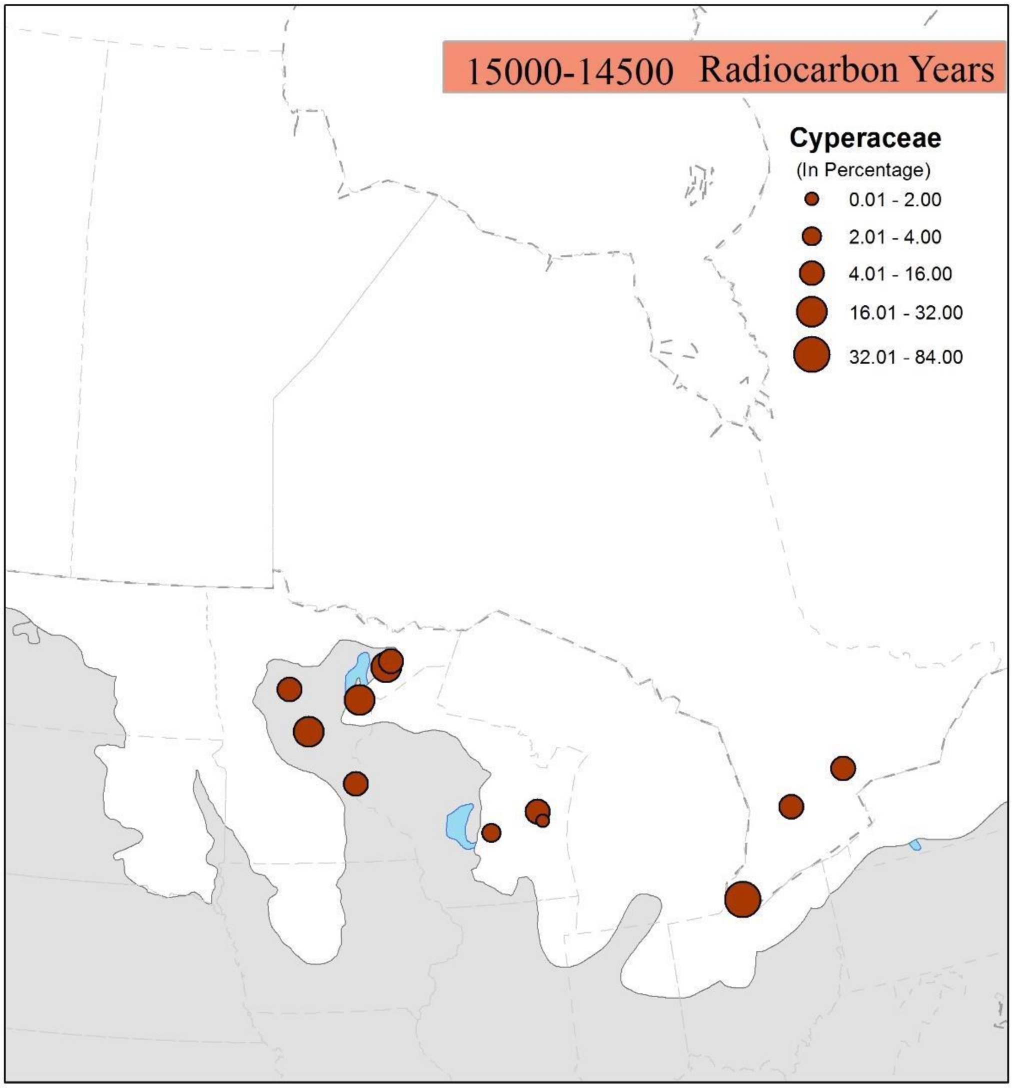

12500-12000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

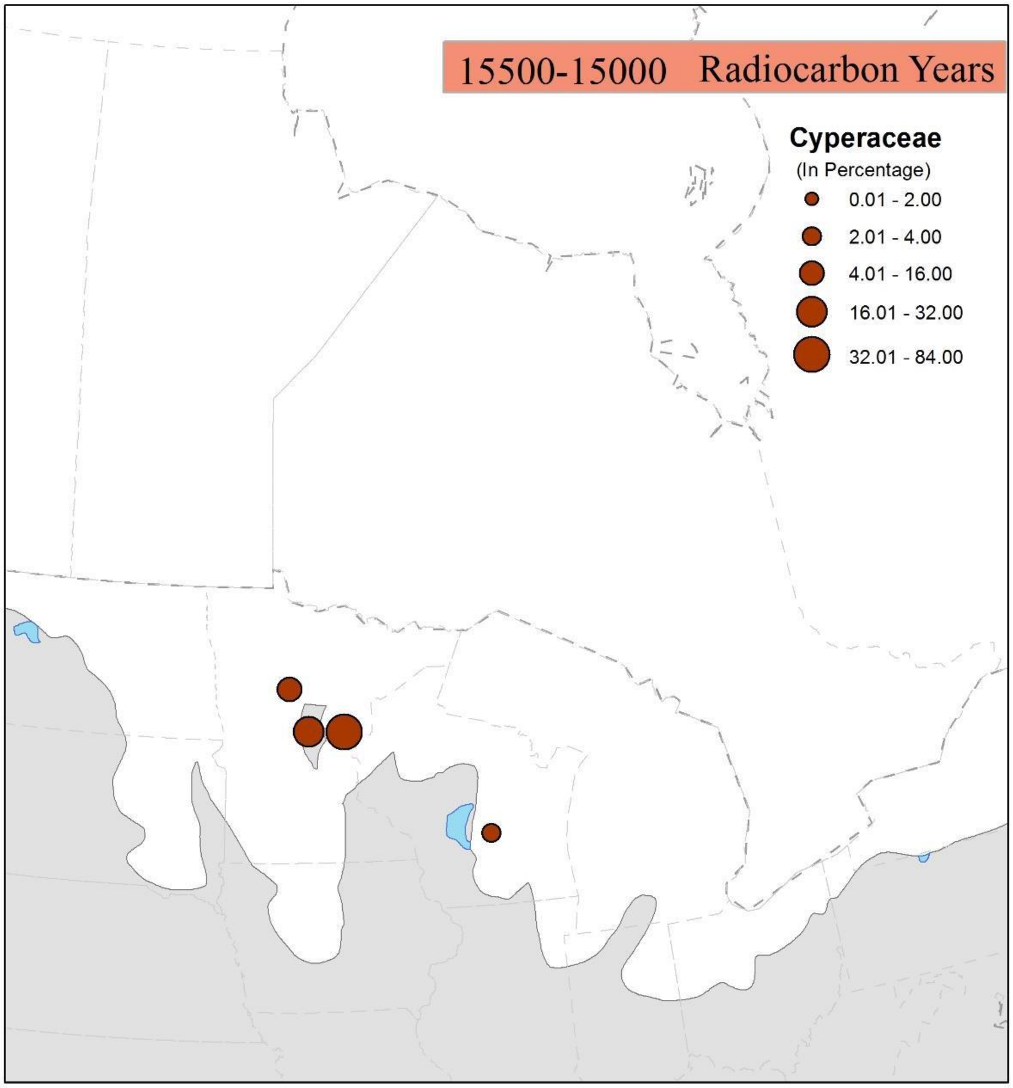

13000-12500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

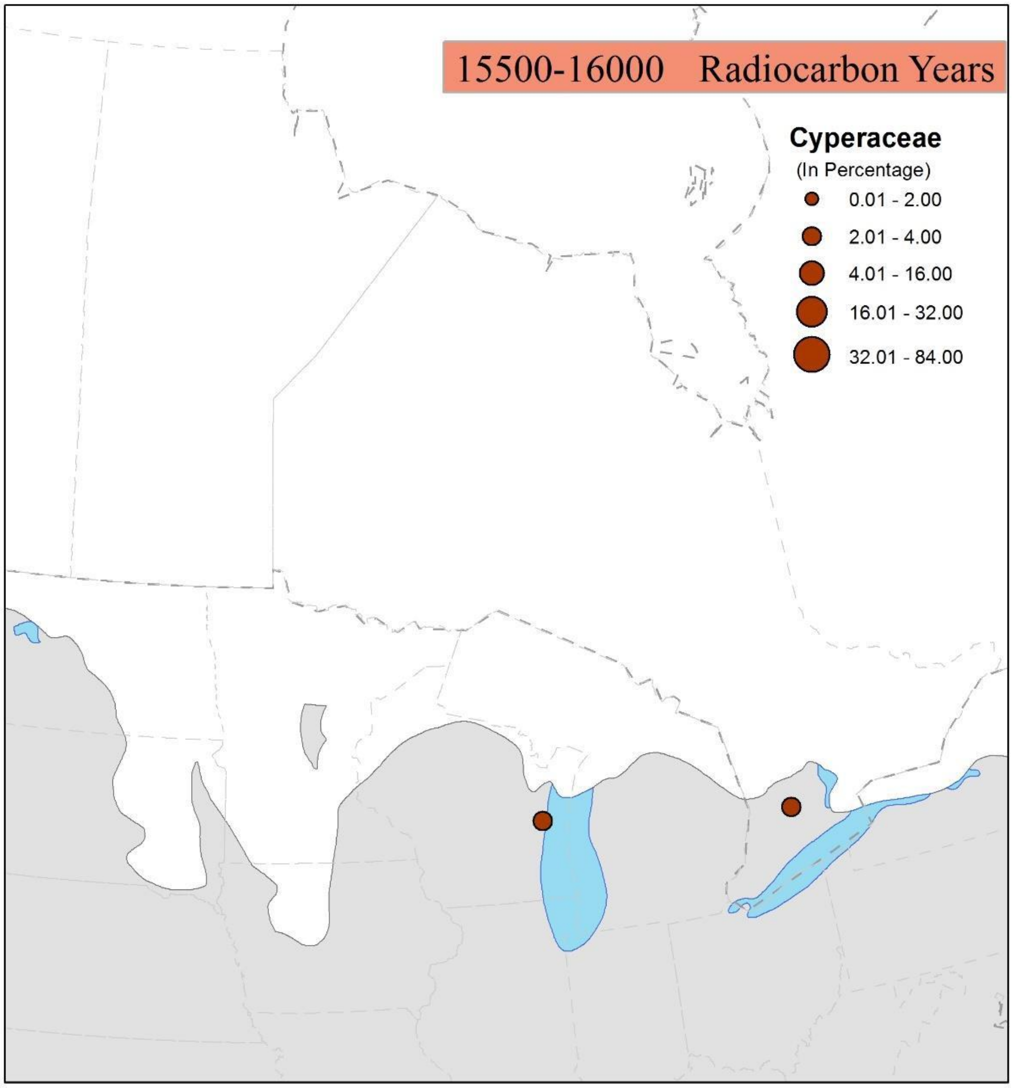

13500-13000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14000-13500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14500-14000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

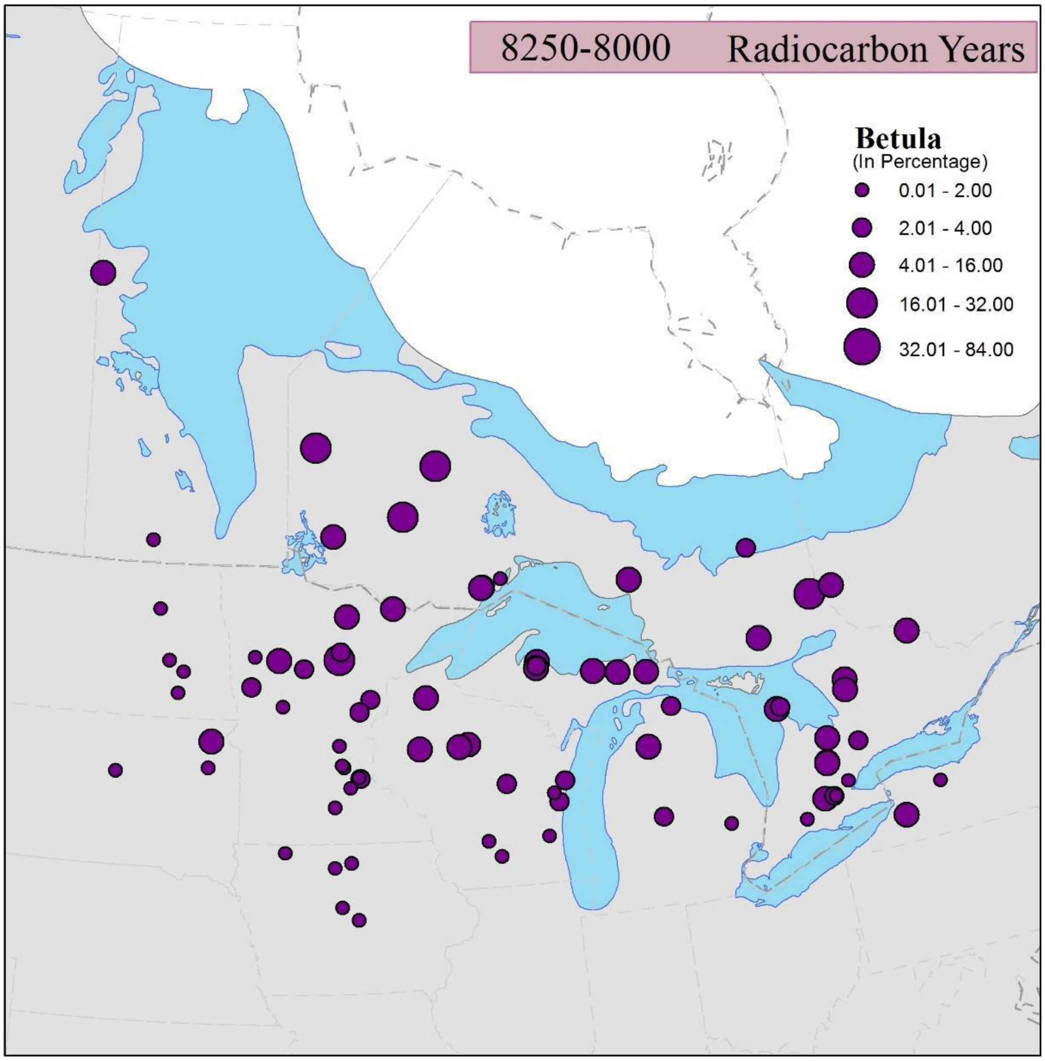

15000-14500 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


15500-15000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

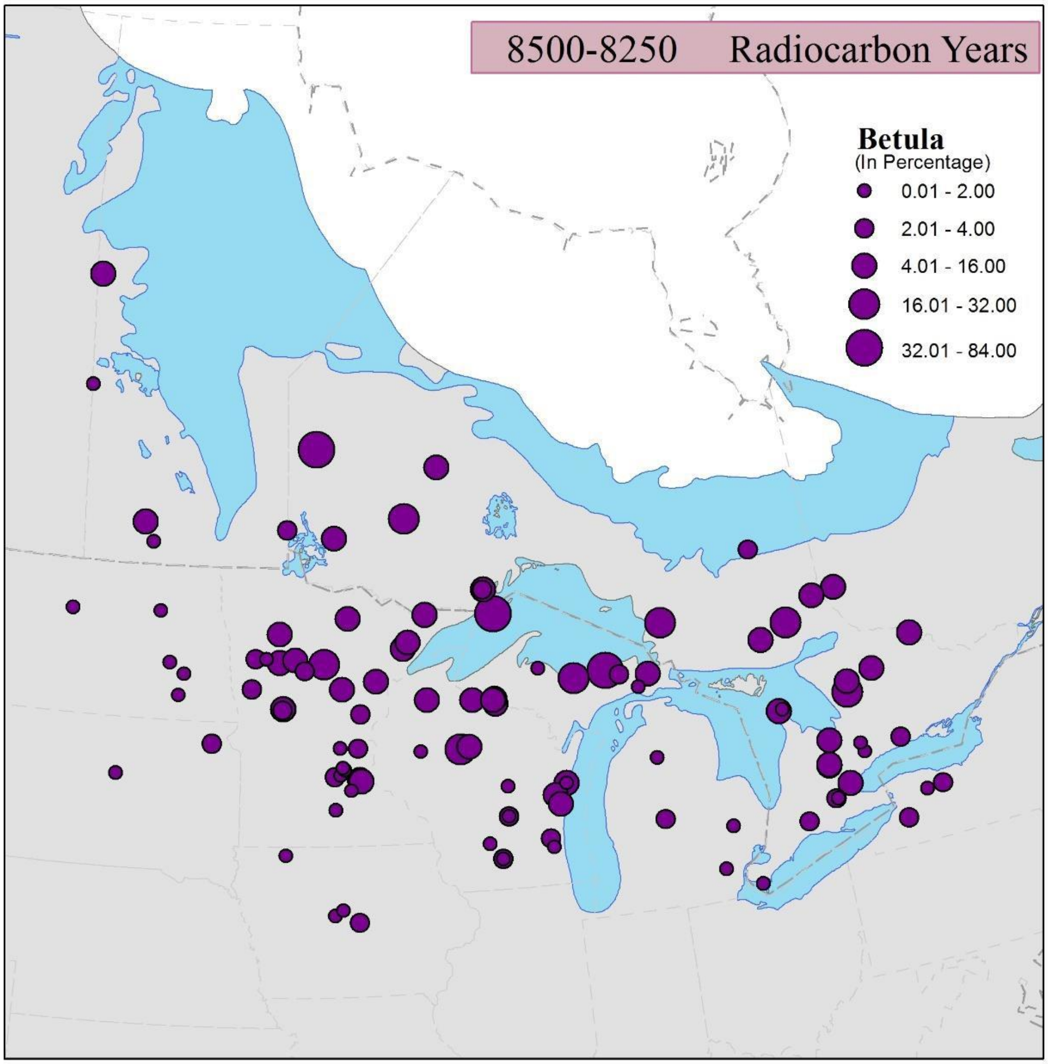

15500-16000 Radiocarbon Years
Cyperaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

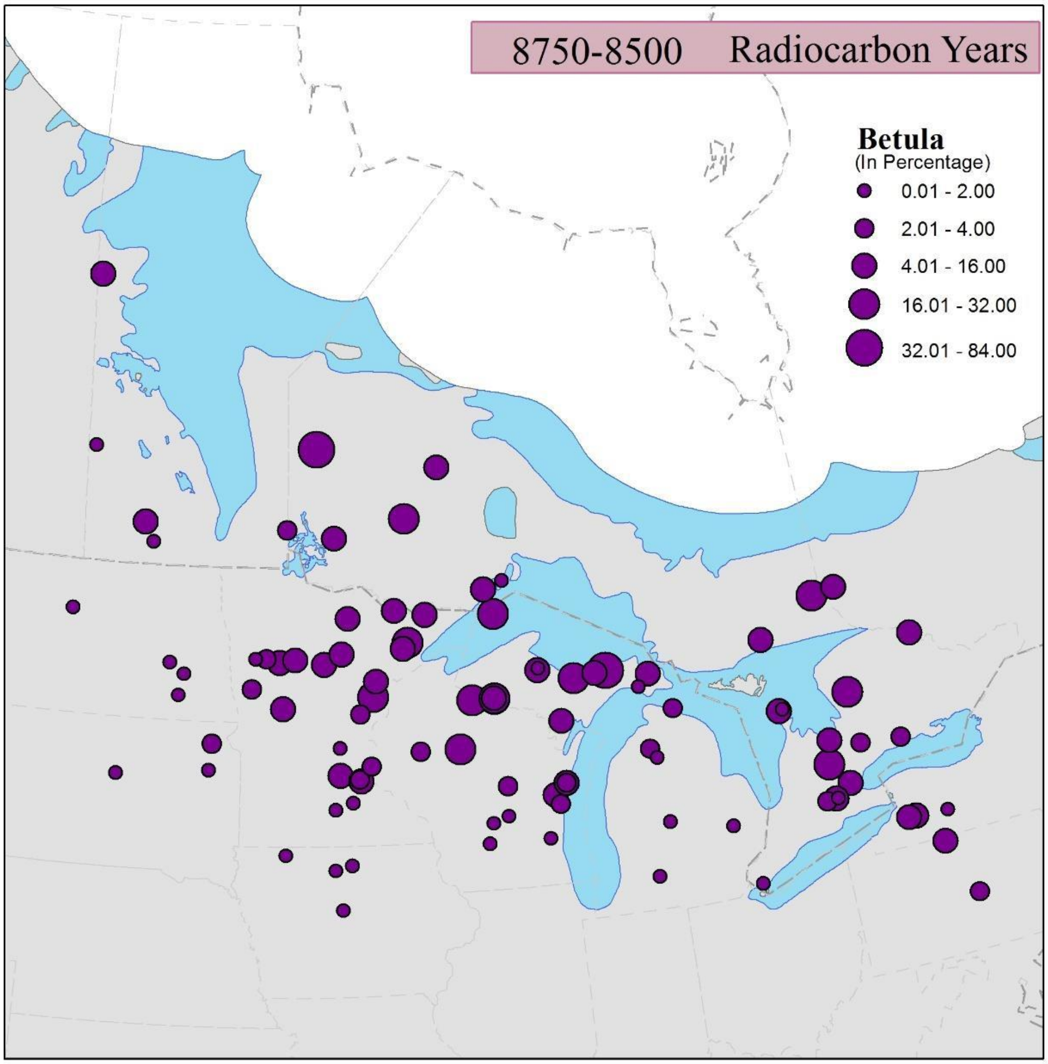
Appendix IV

Pollen abundance of *Betula*

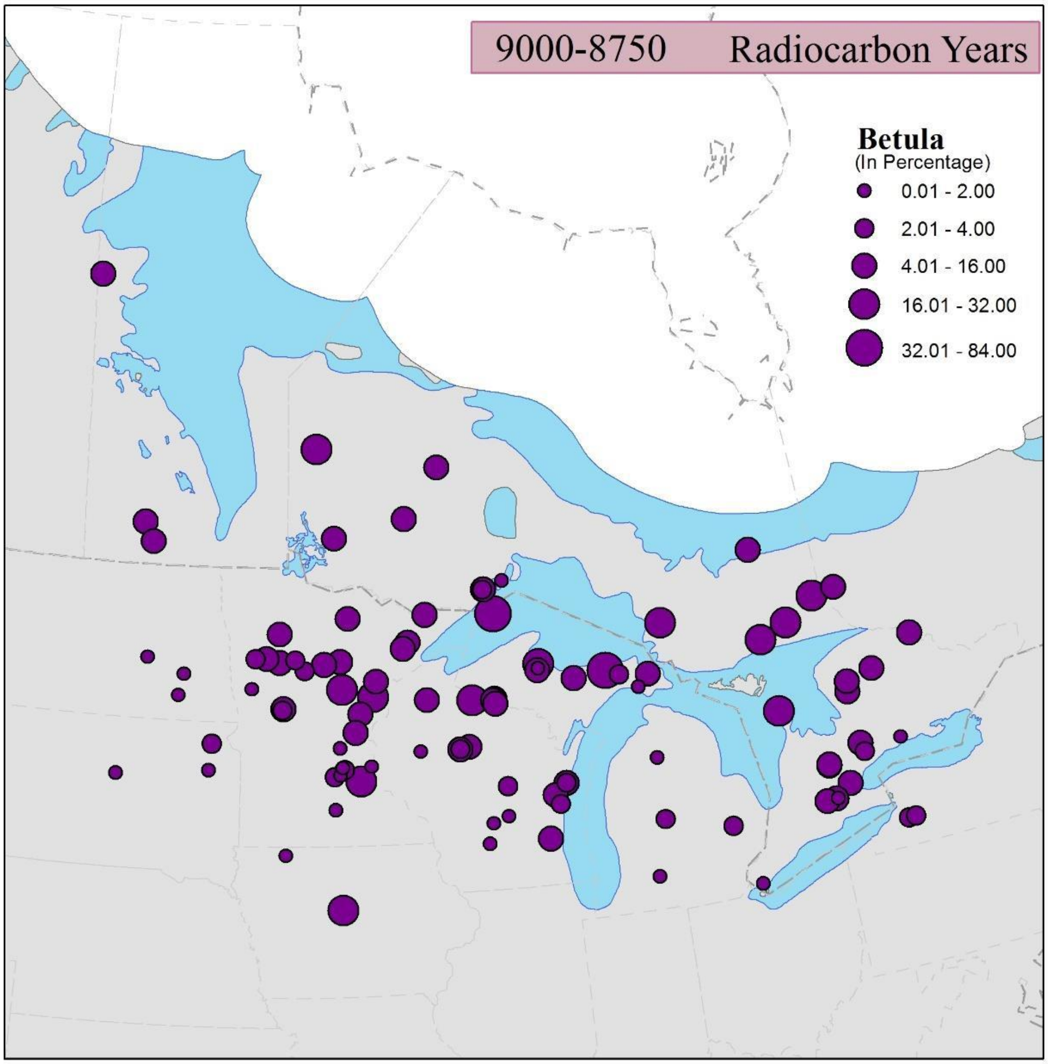


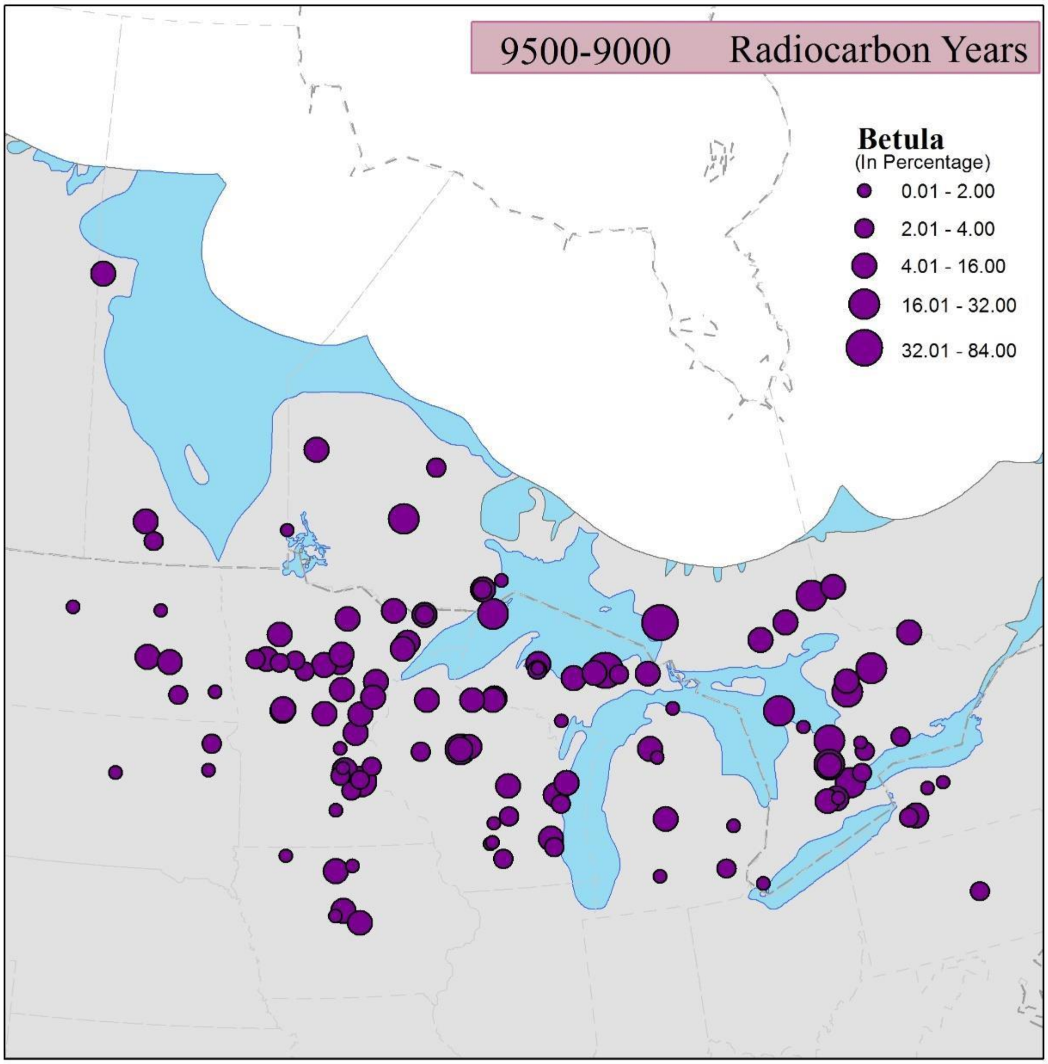
8250-8000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

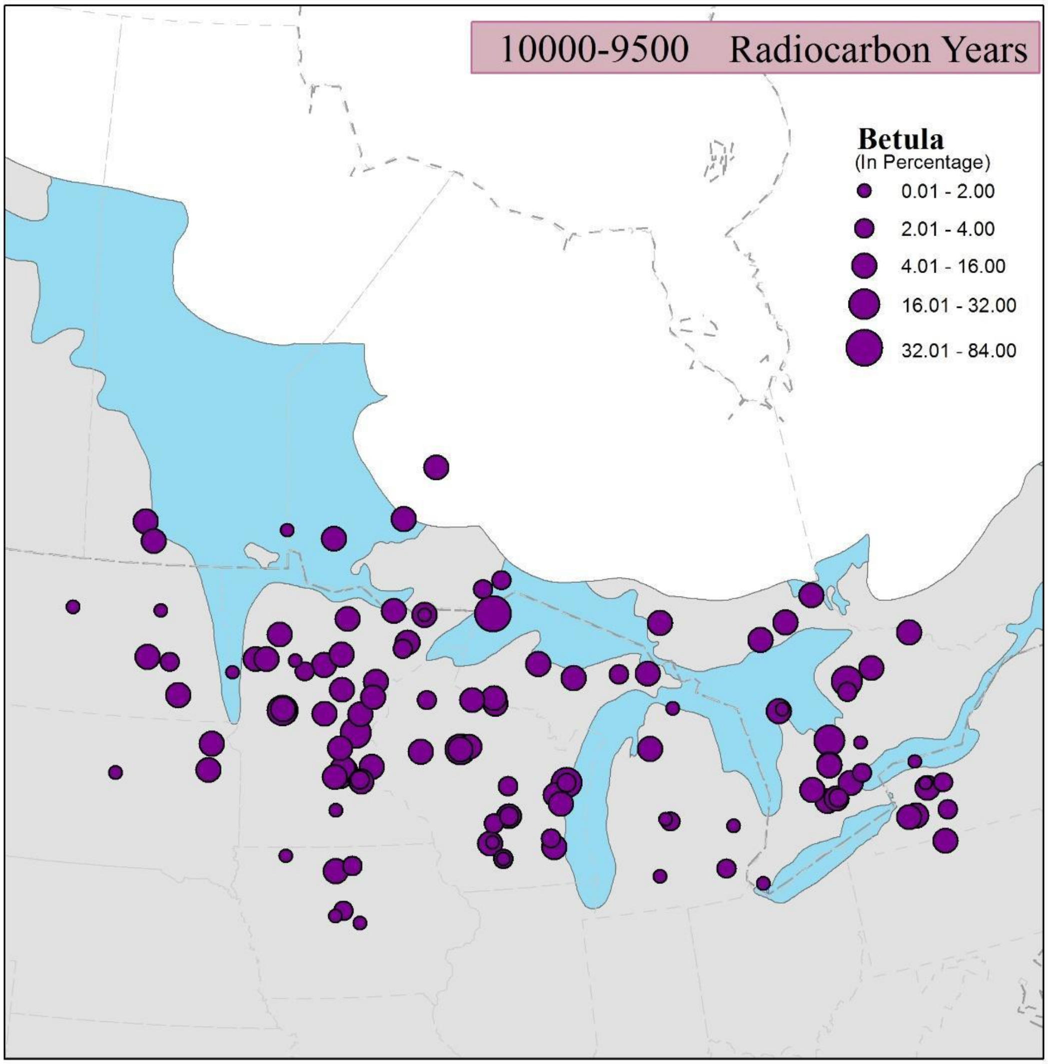

8500-8250 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

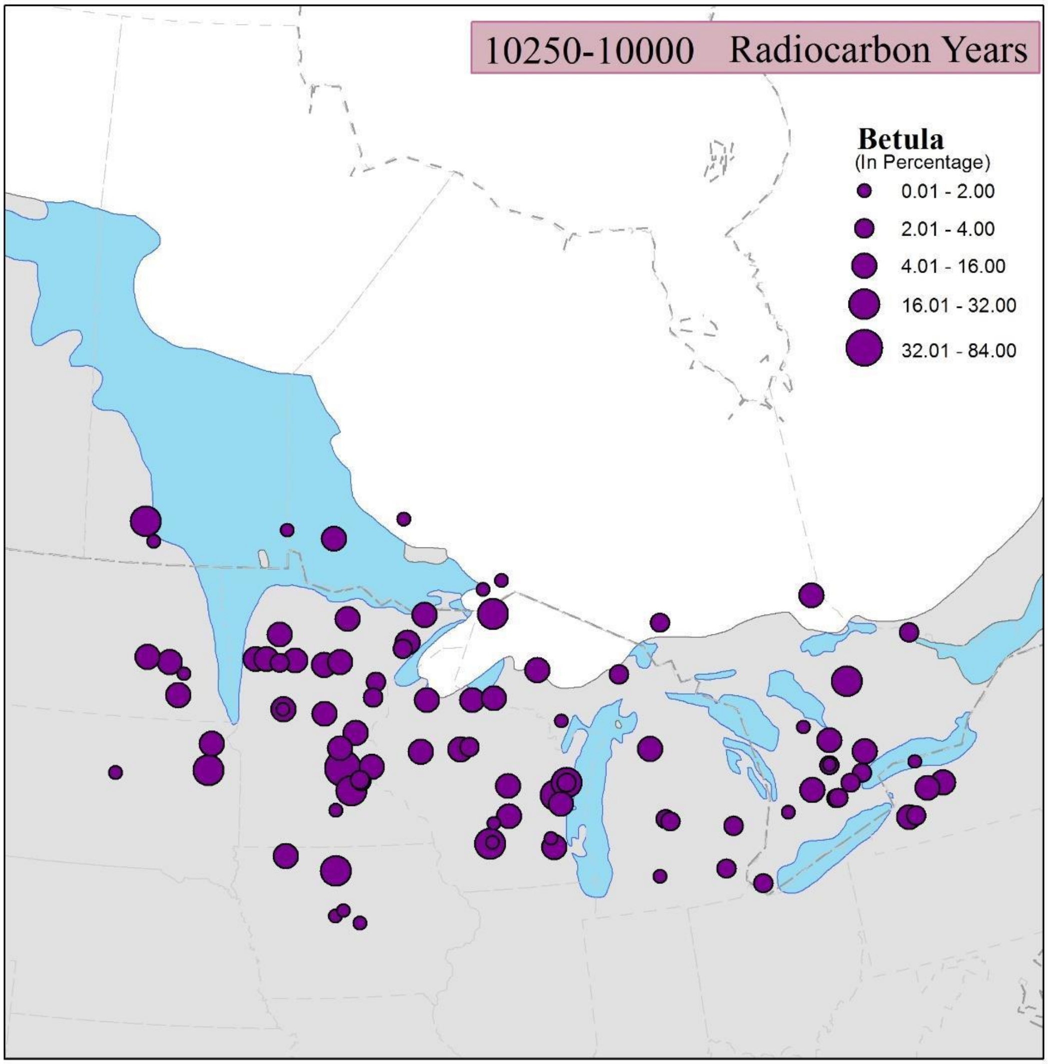


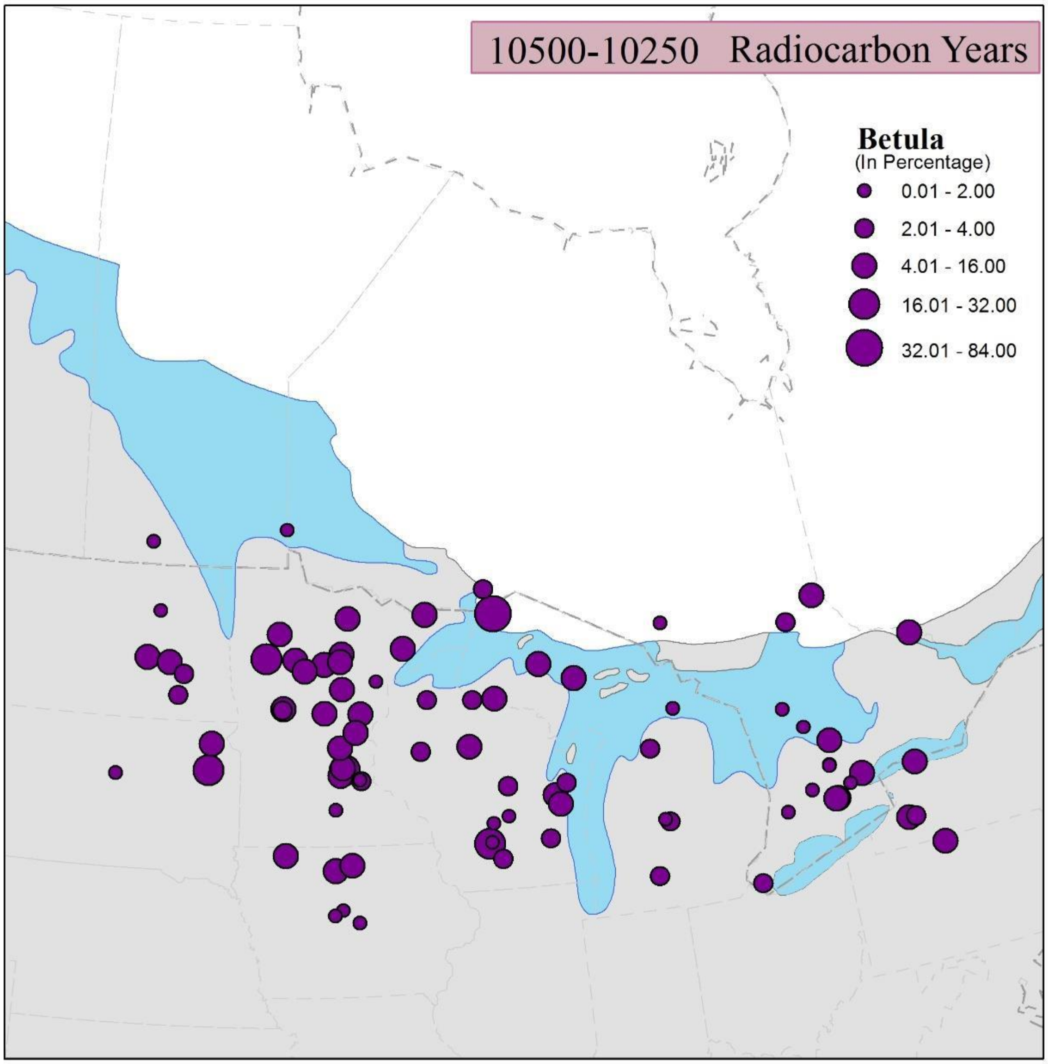
8750-8500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

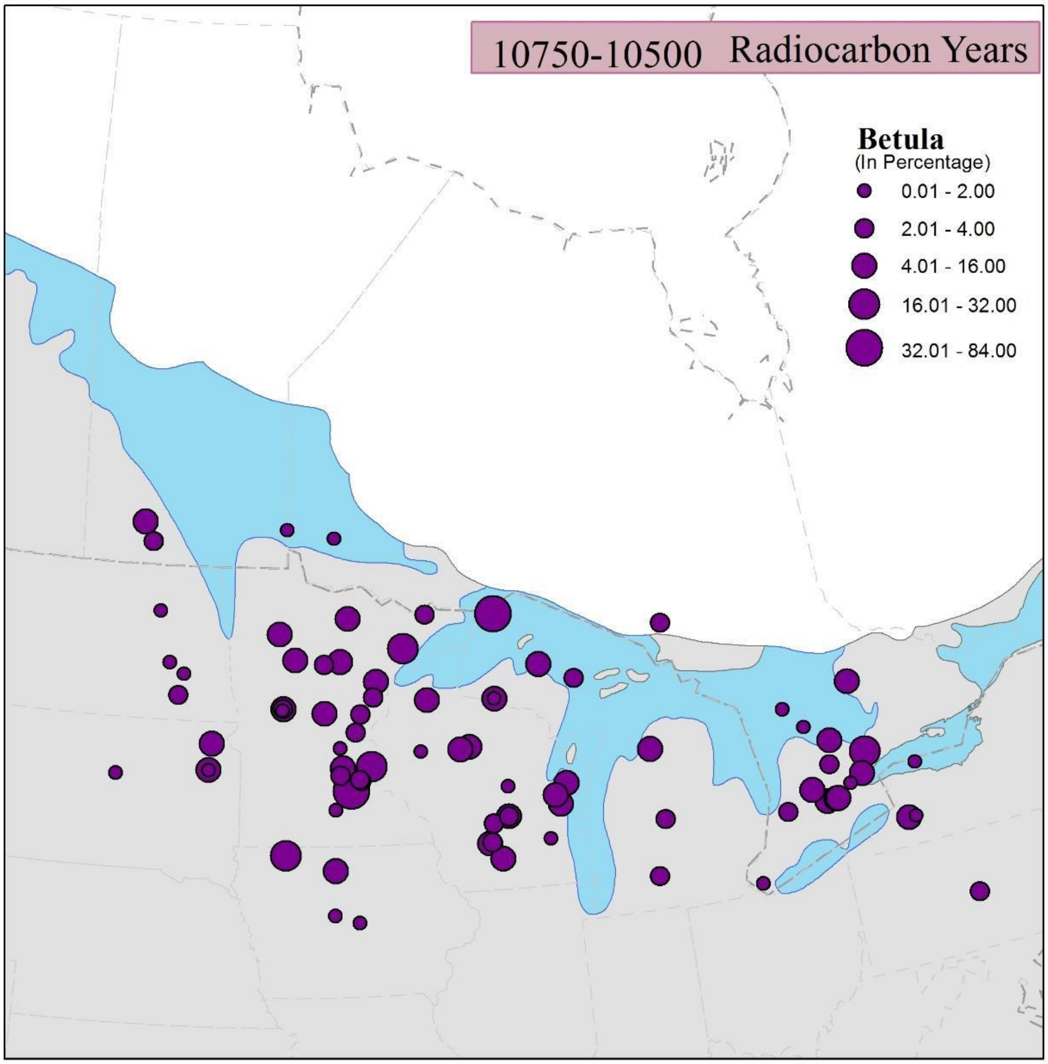

9000-8750 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

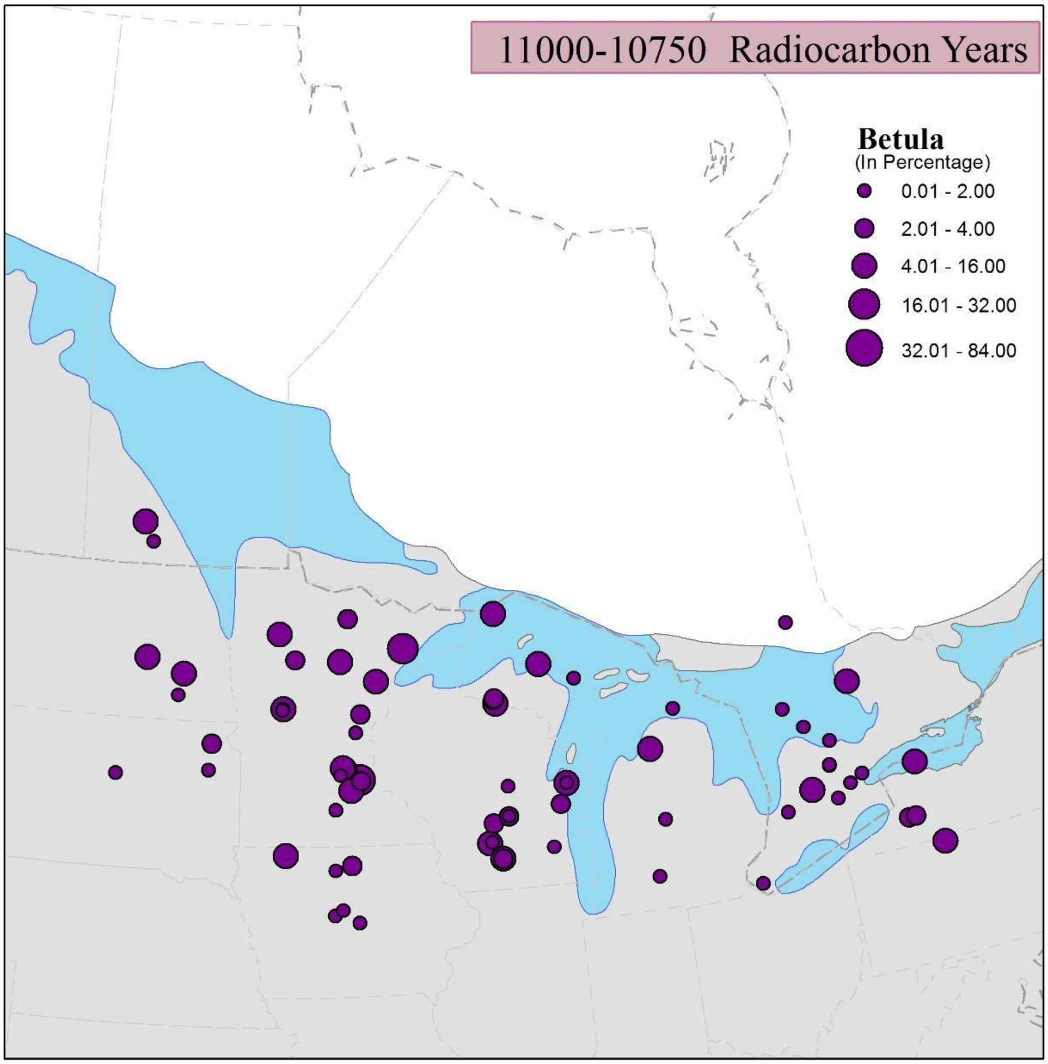

9500-9000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

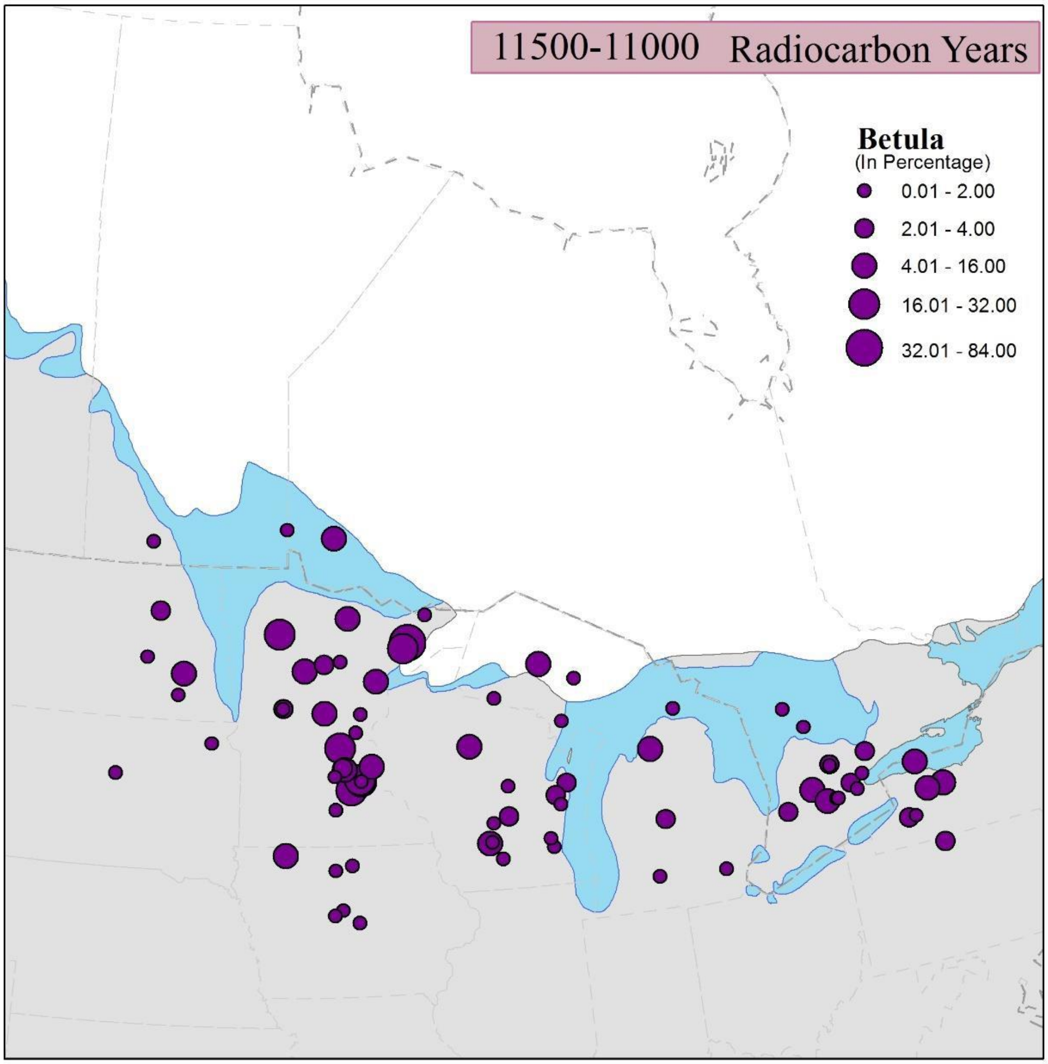

10000-9500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

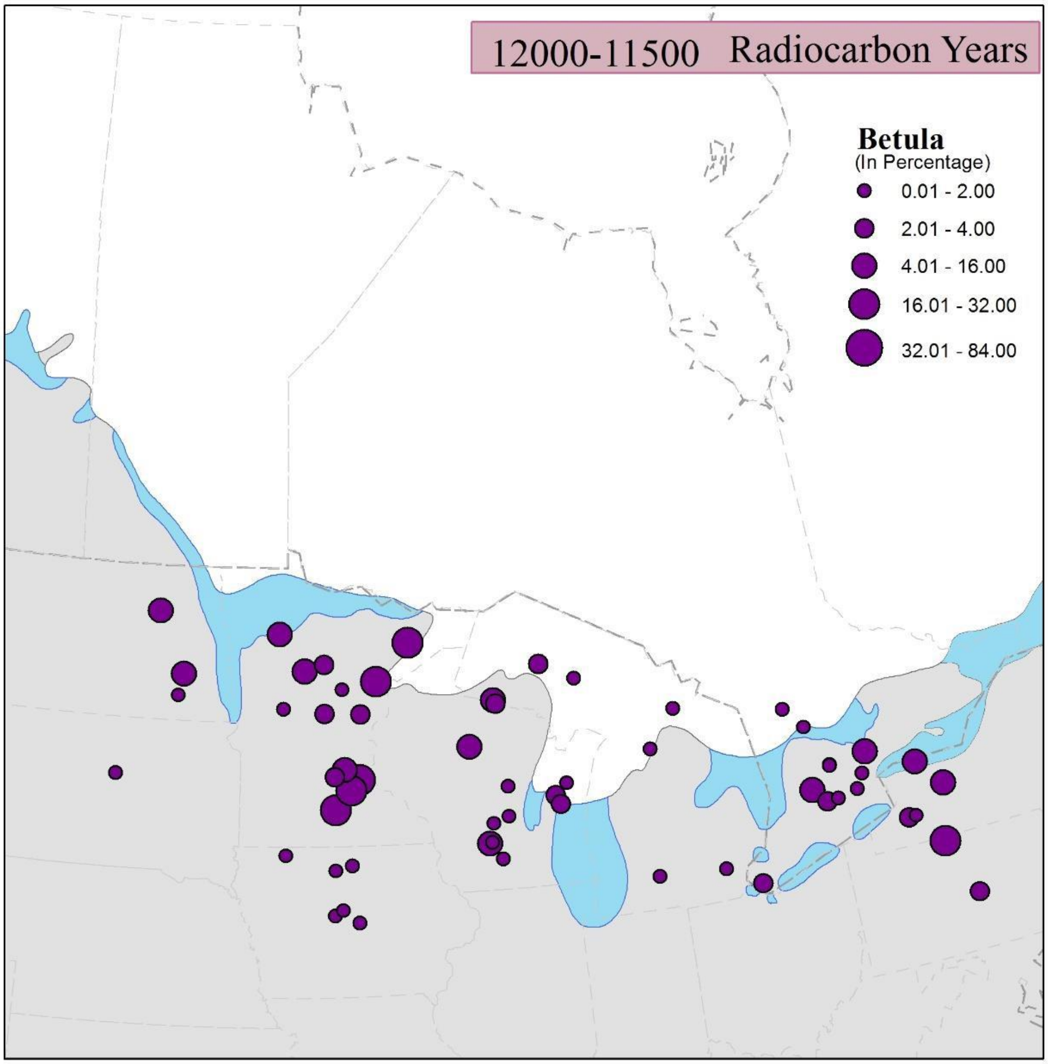

10250-10000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

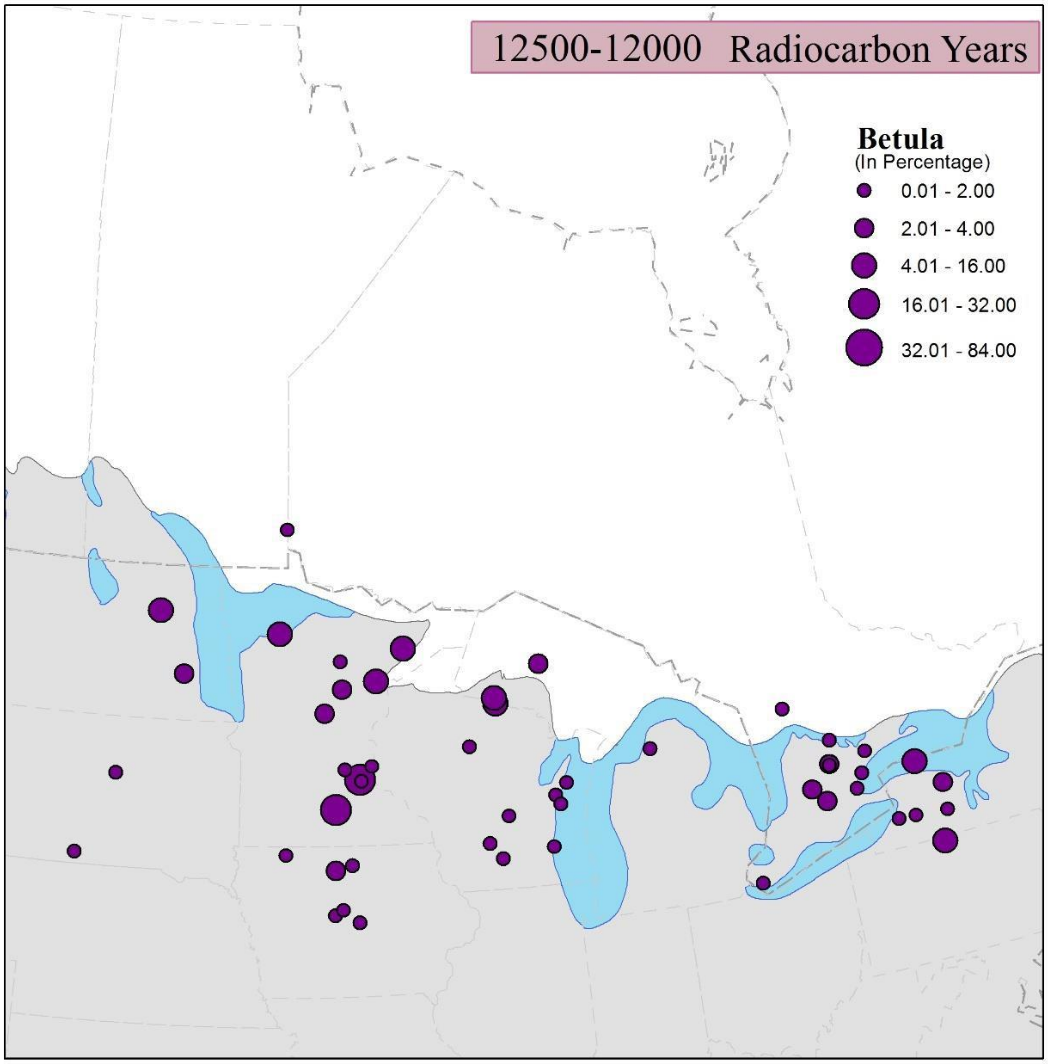

10500-10250 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

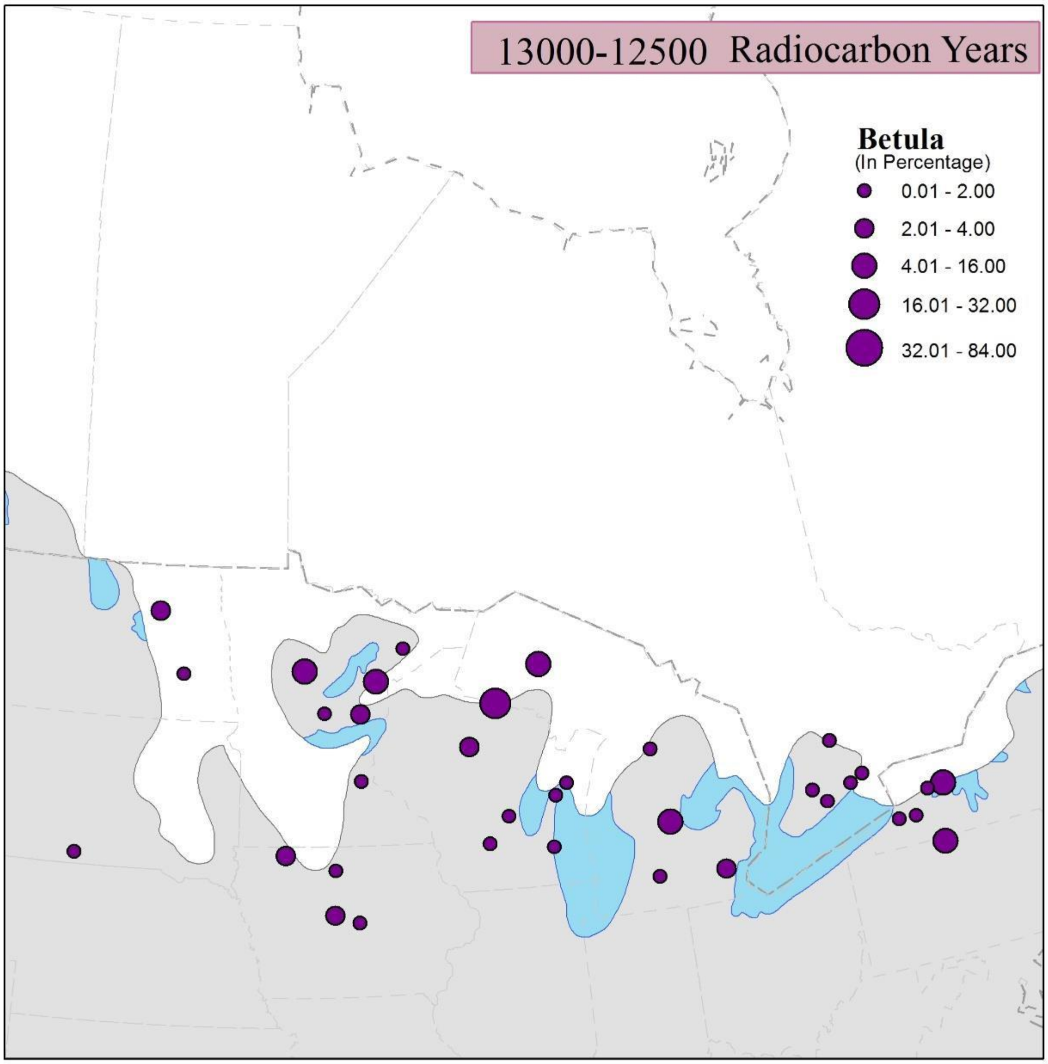

10750-10500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

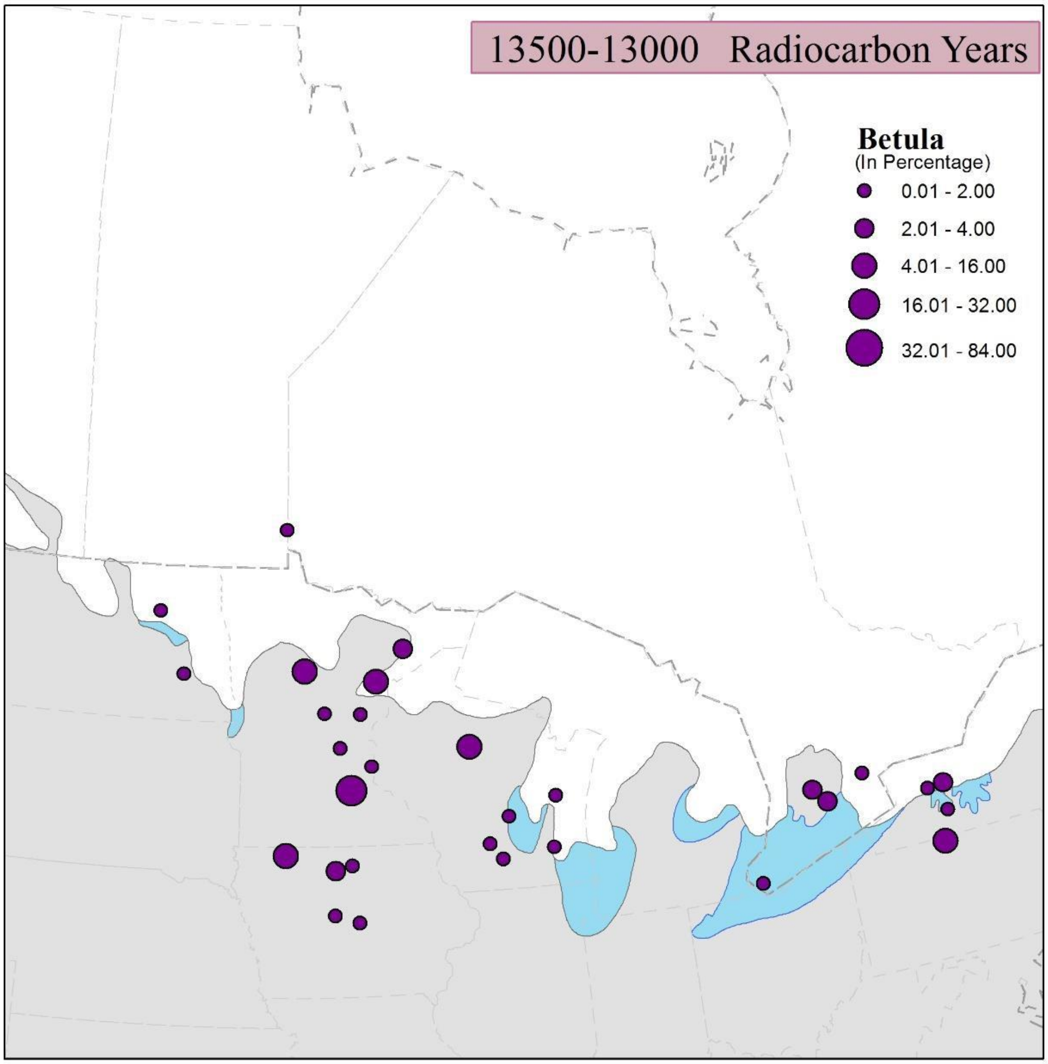

11000-10750 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


11500-11000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

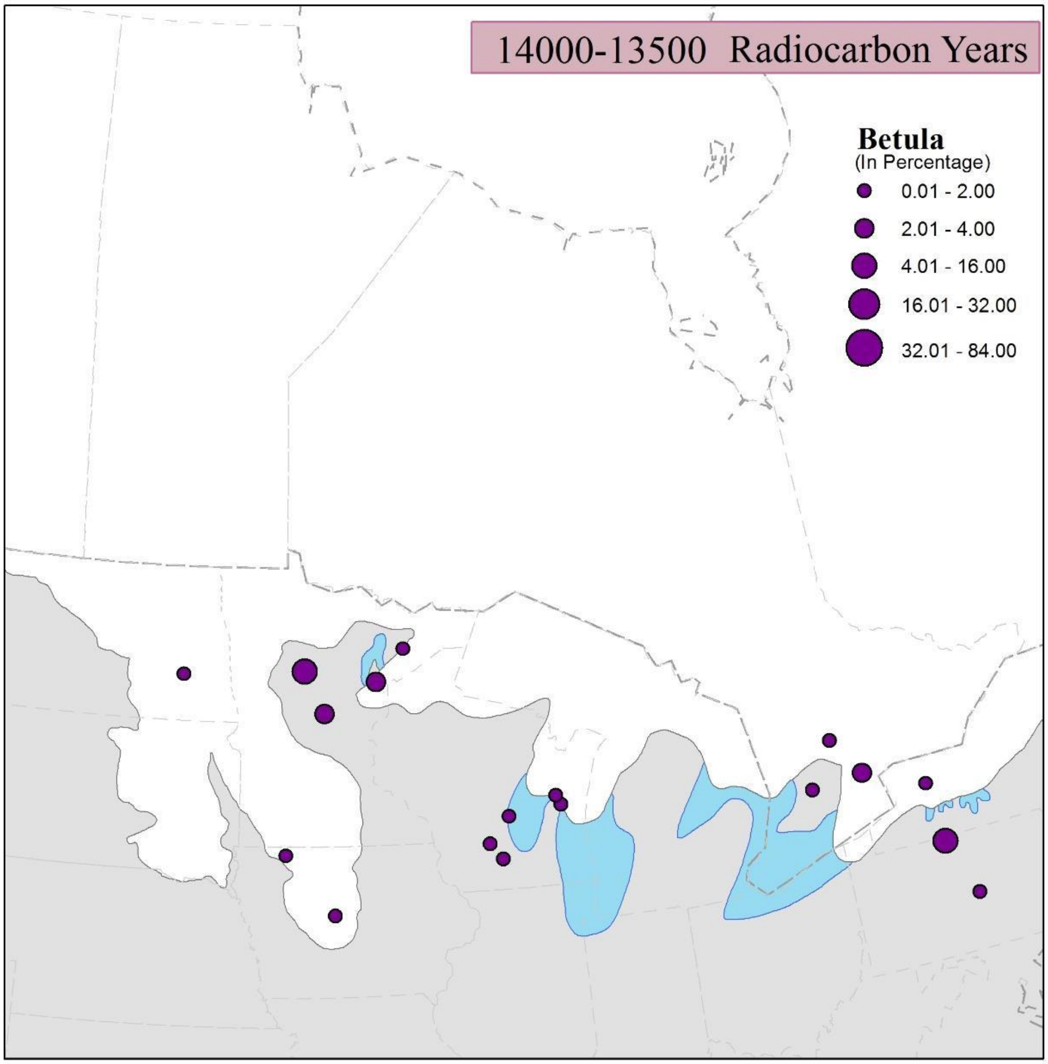

12000-11500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

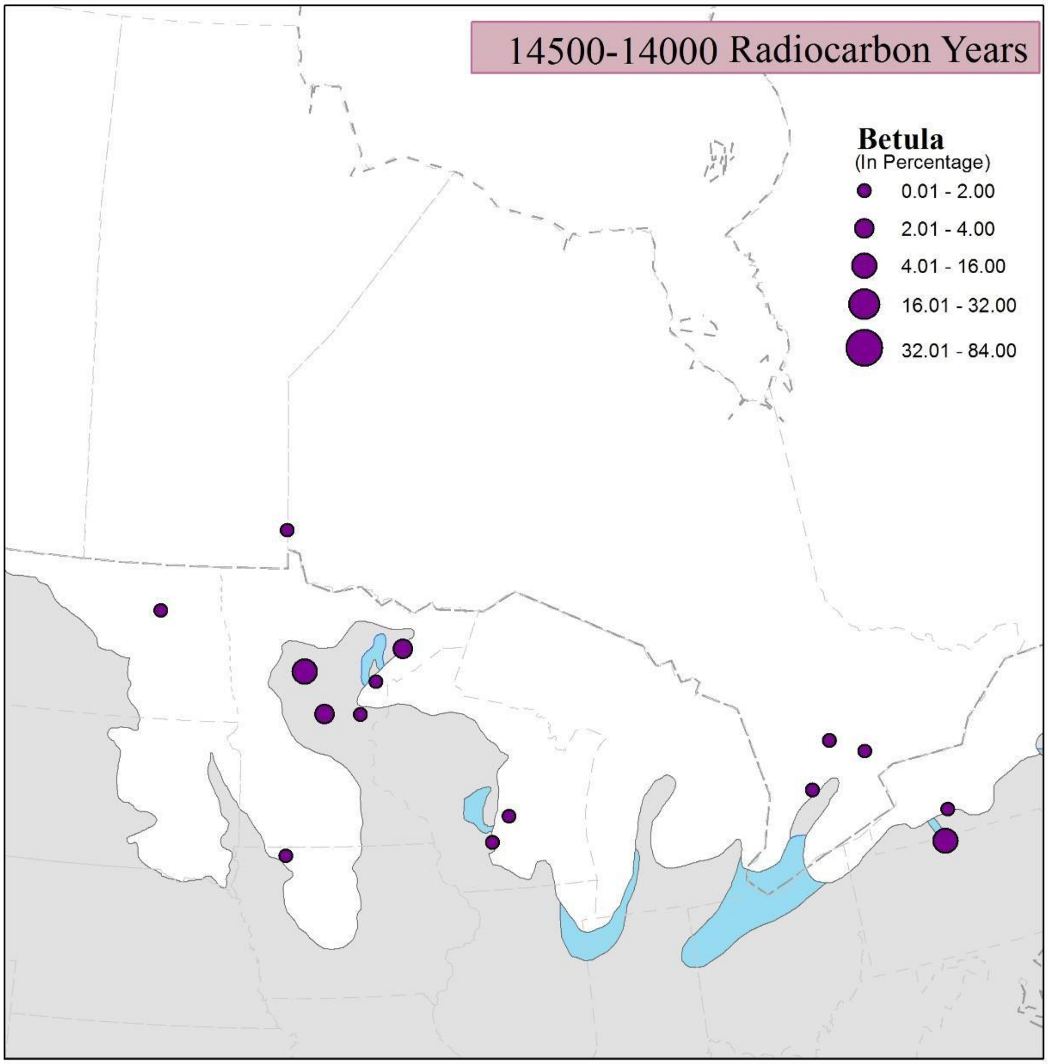

12500-12000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

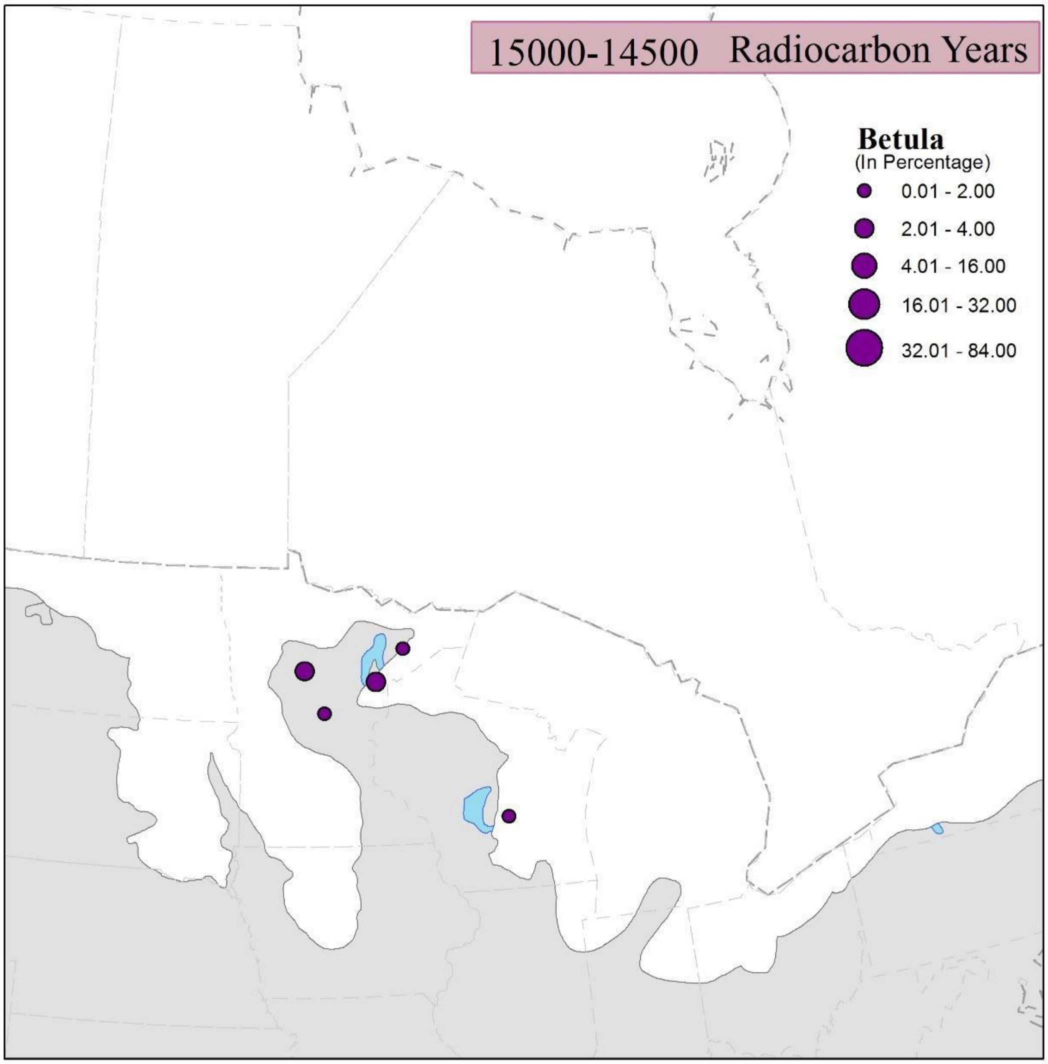

13000-12500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

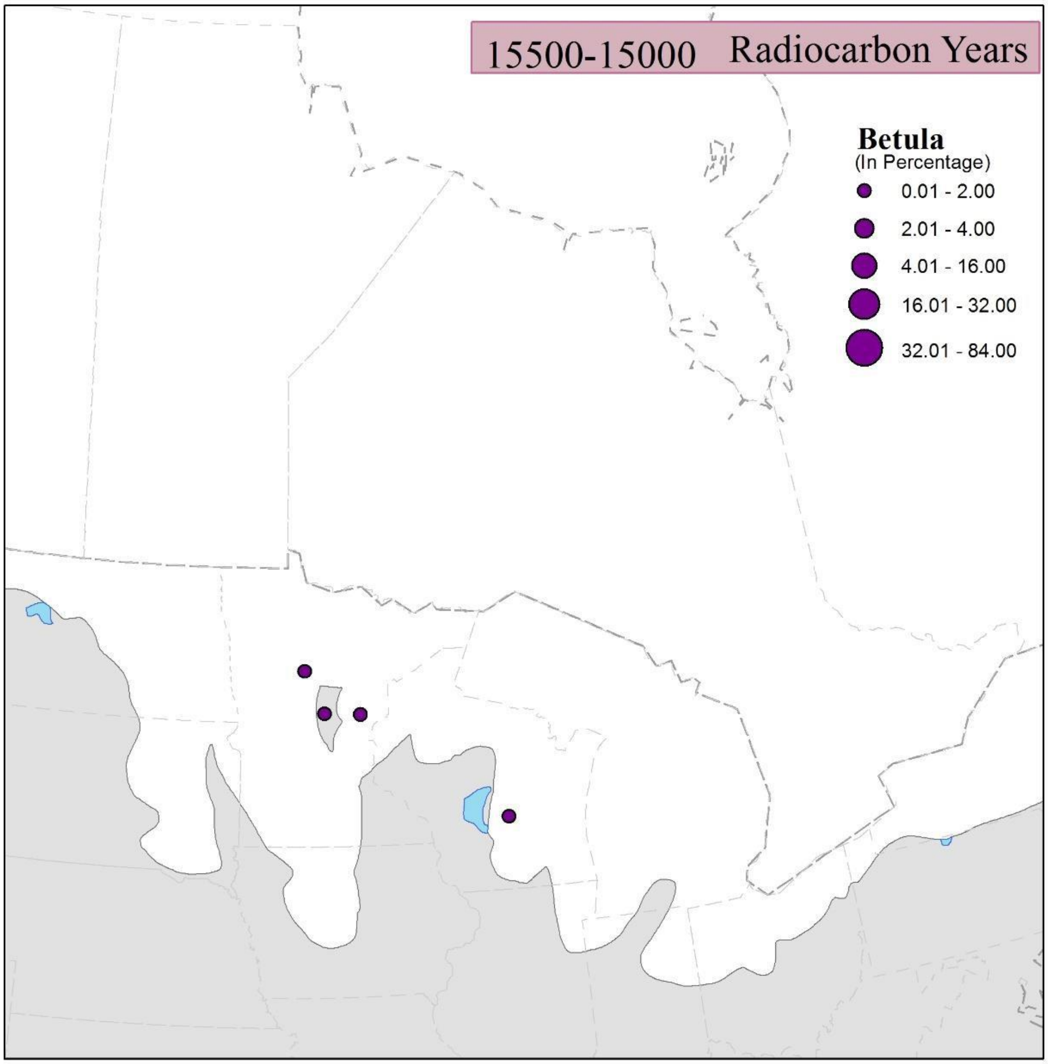


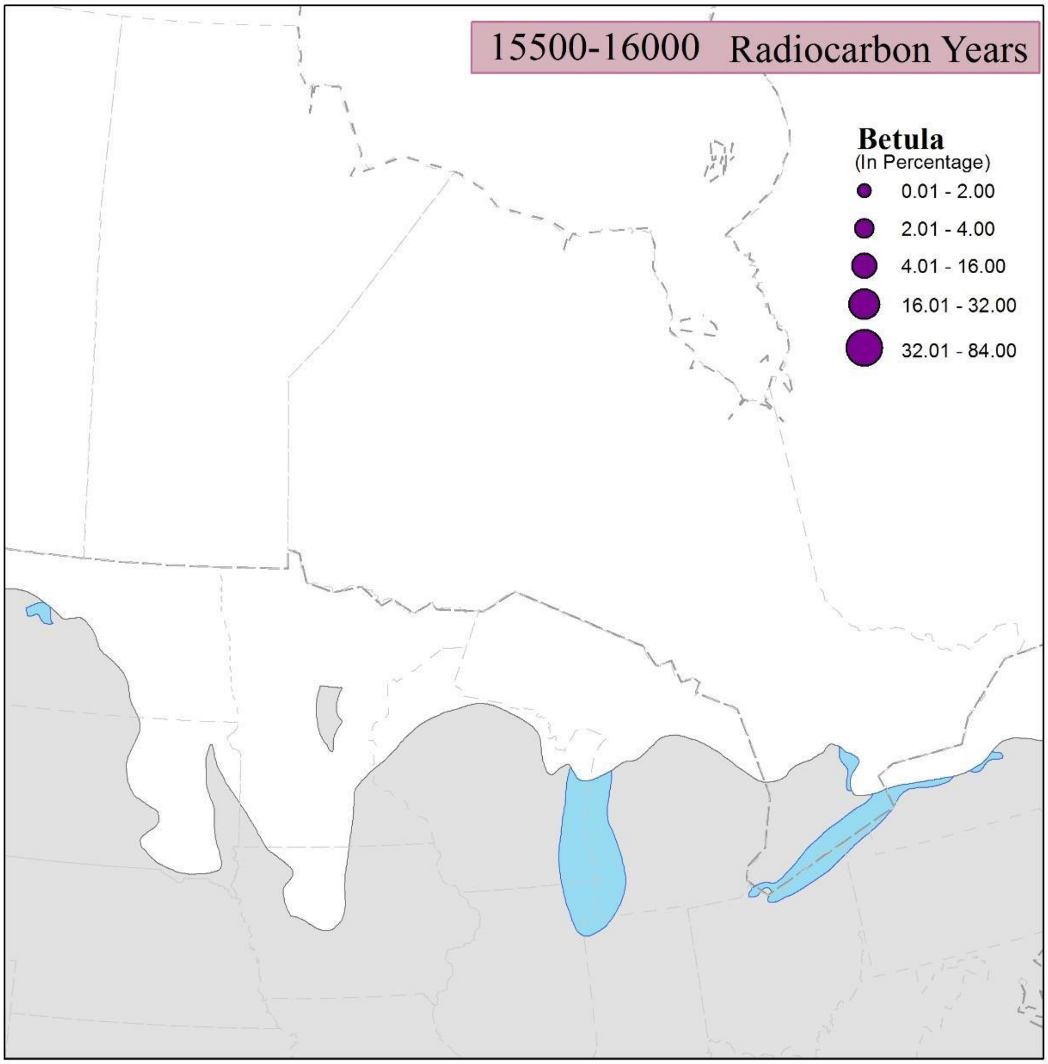
13500-13000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14000-13500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14500-14000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

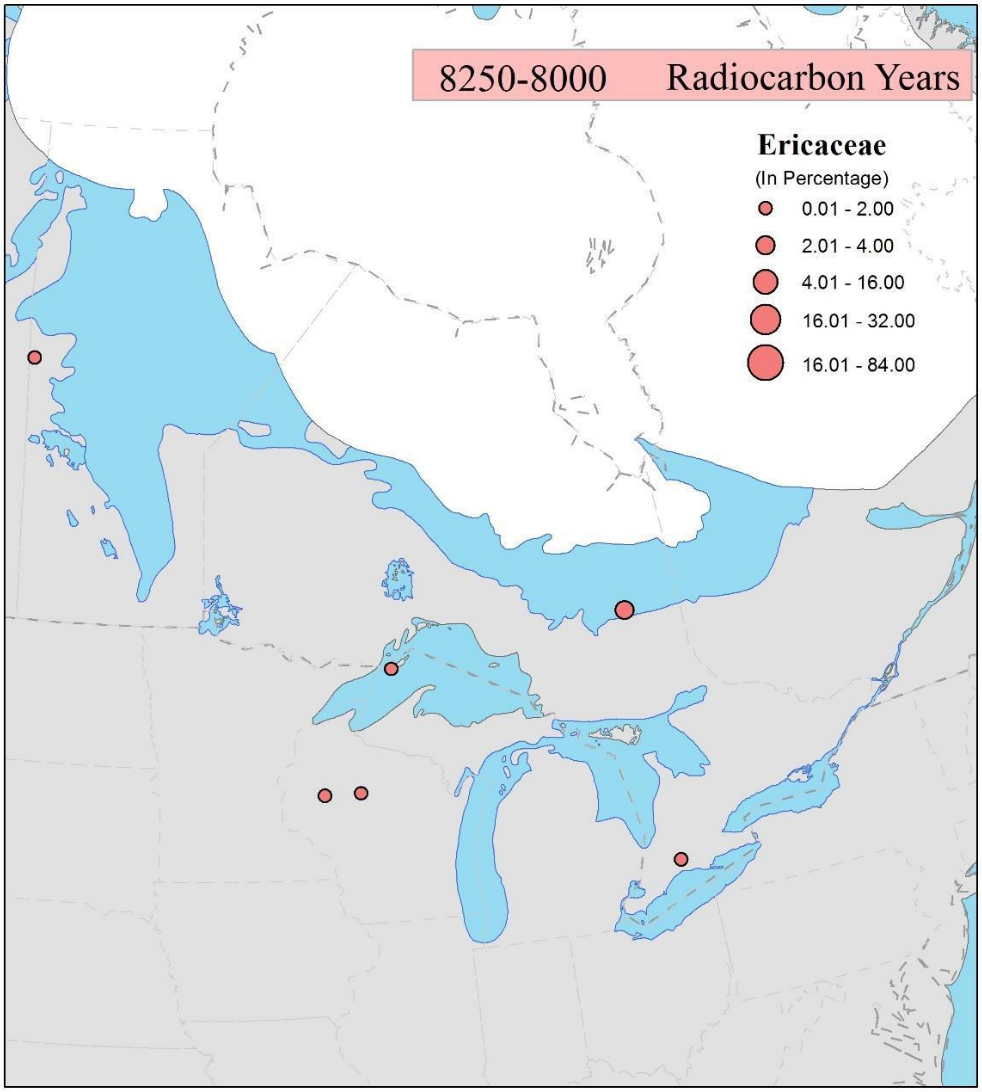

15000-14500 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

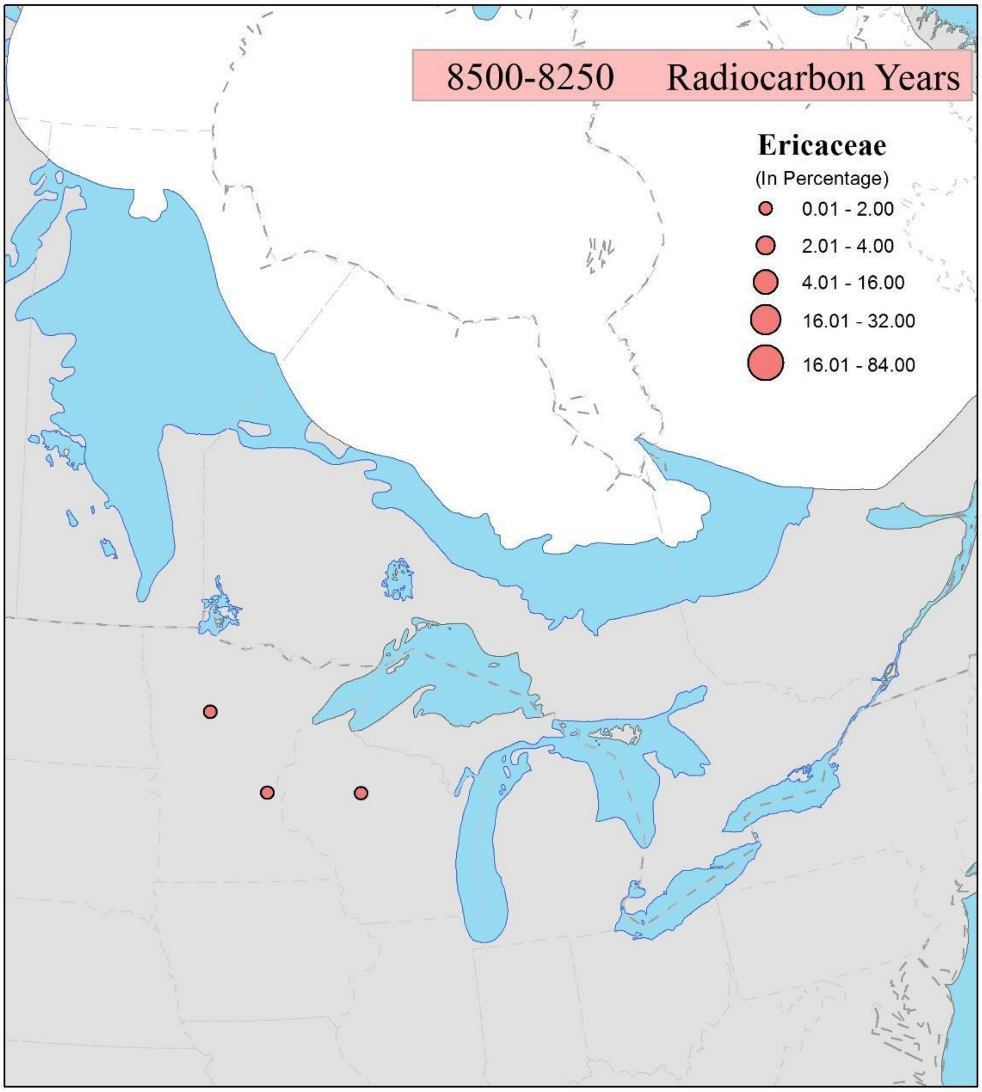

15500-15000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

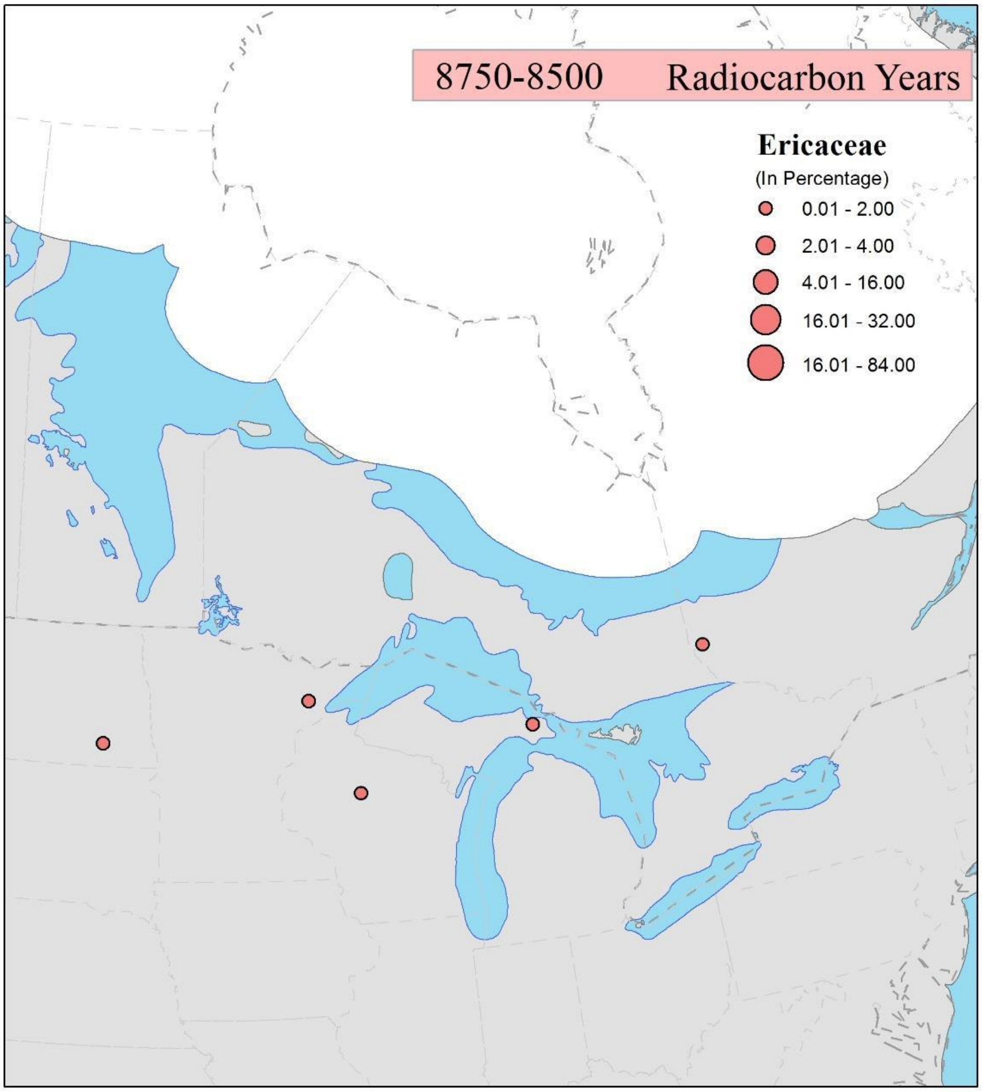

15500-16000 Radiocarbon Years
Betula
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

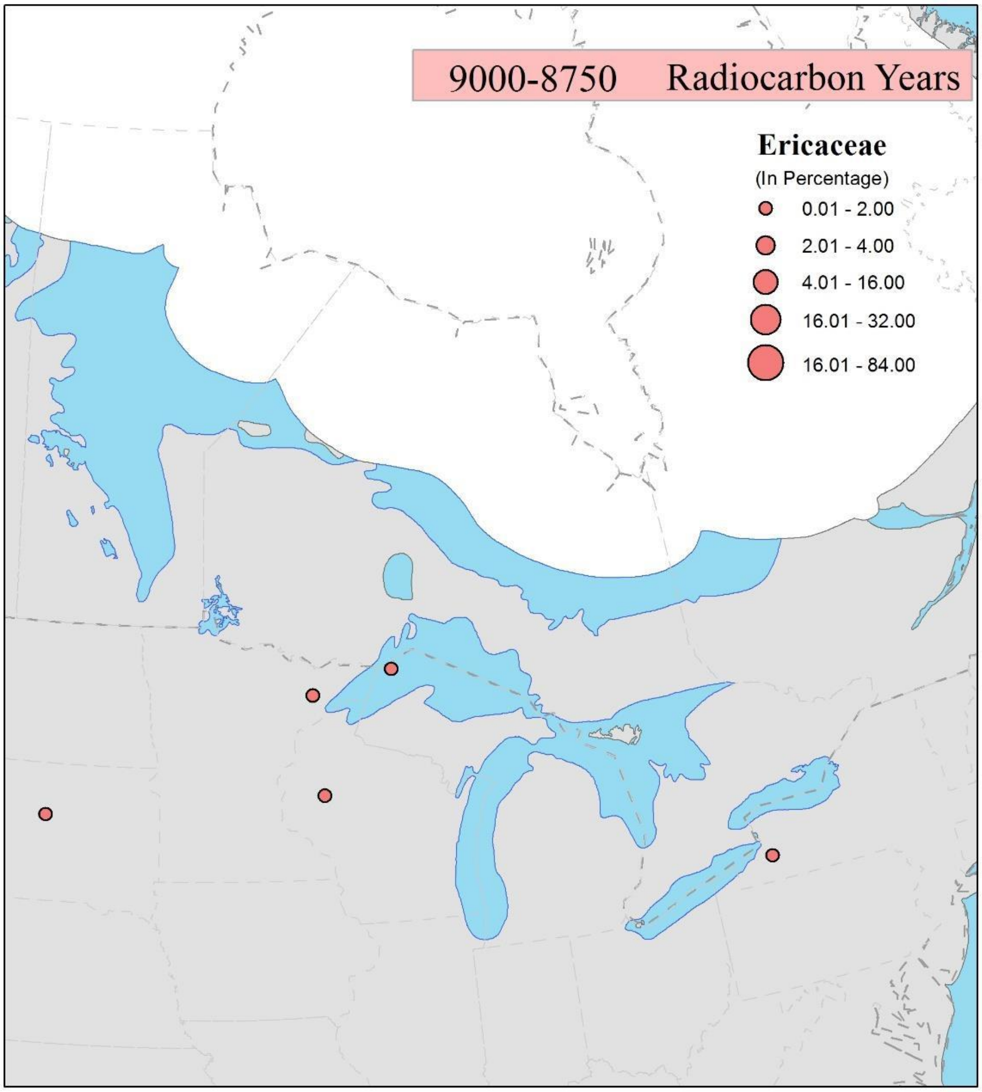
Appendix V

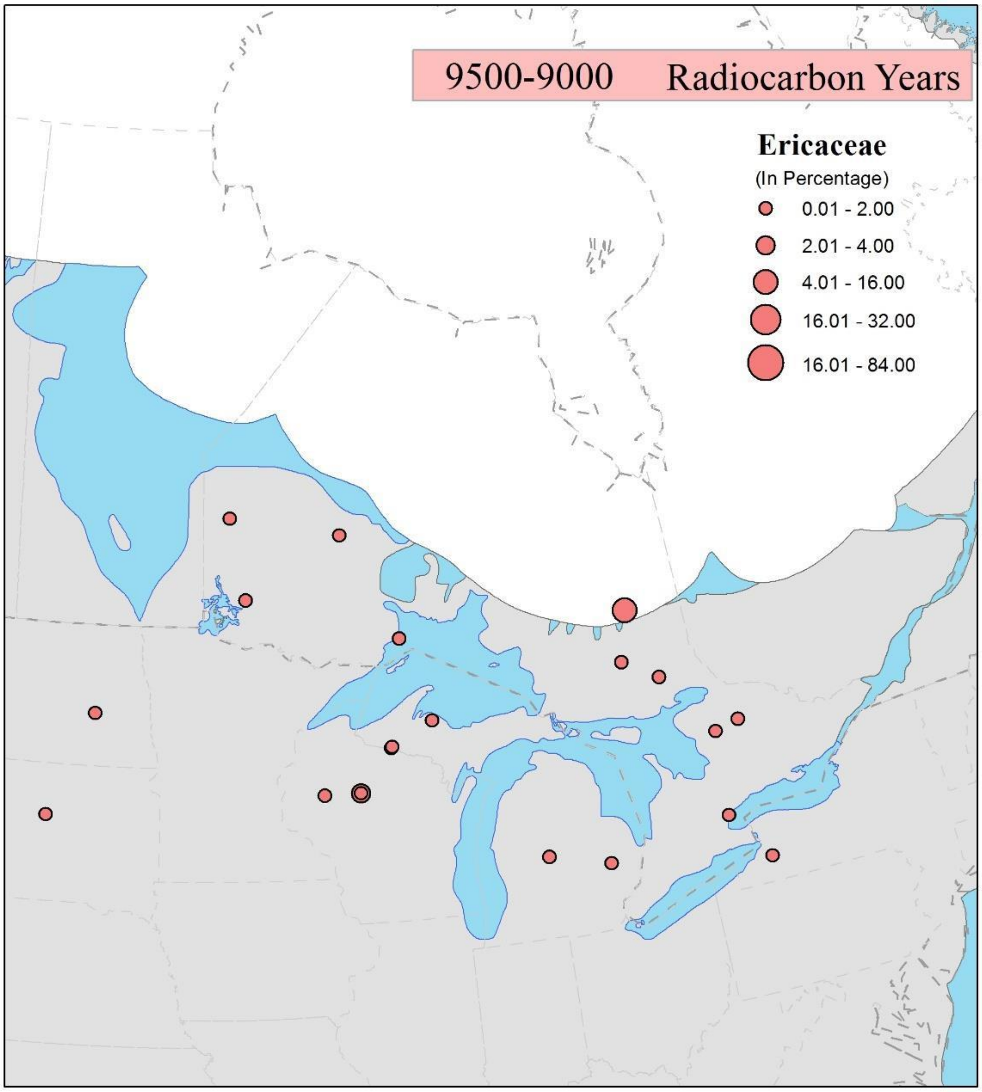
Pollen abundance of Ericaceae


8250-8000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

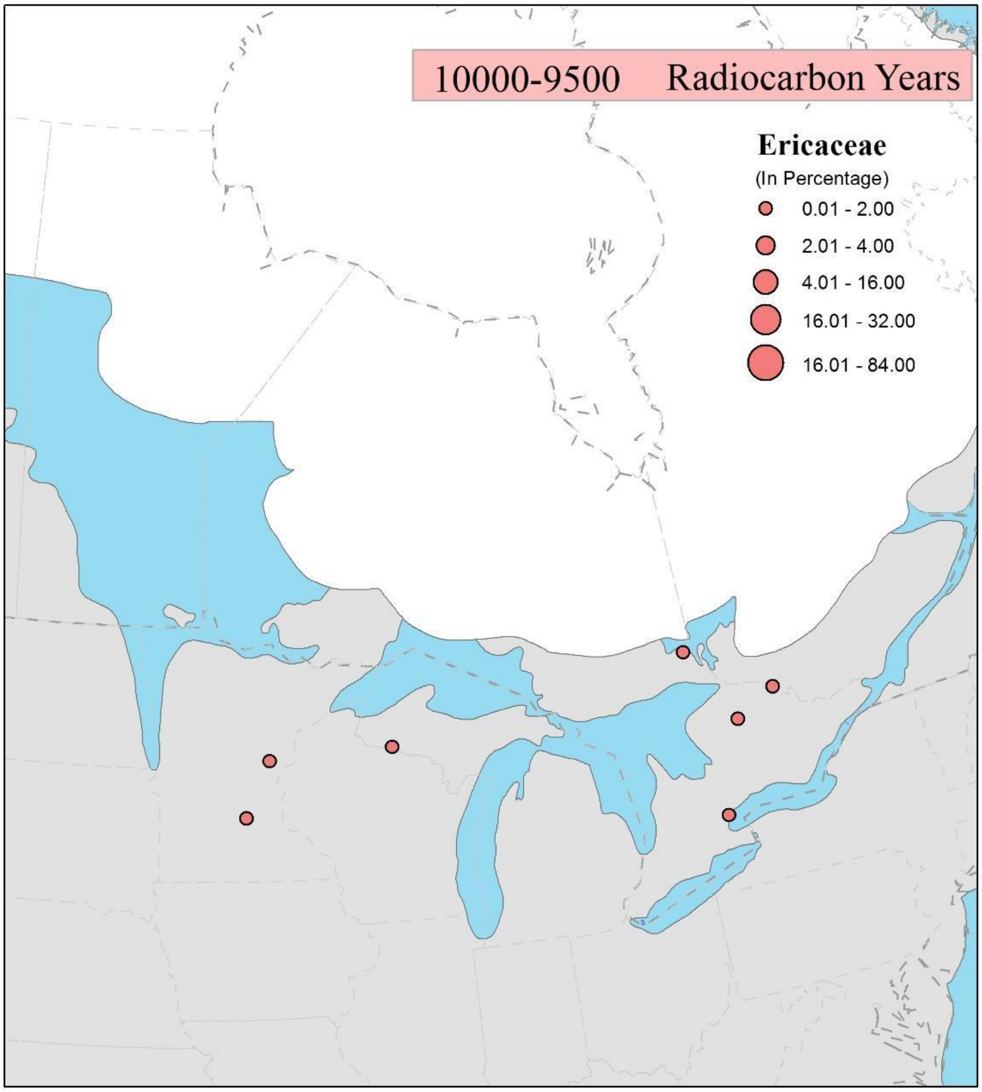

8500-8250 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

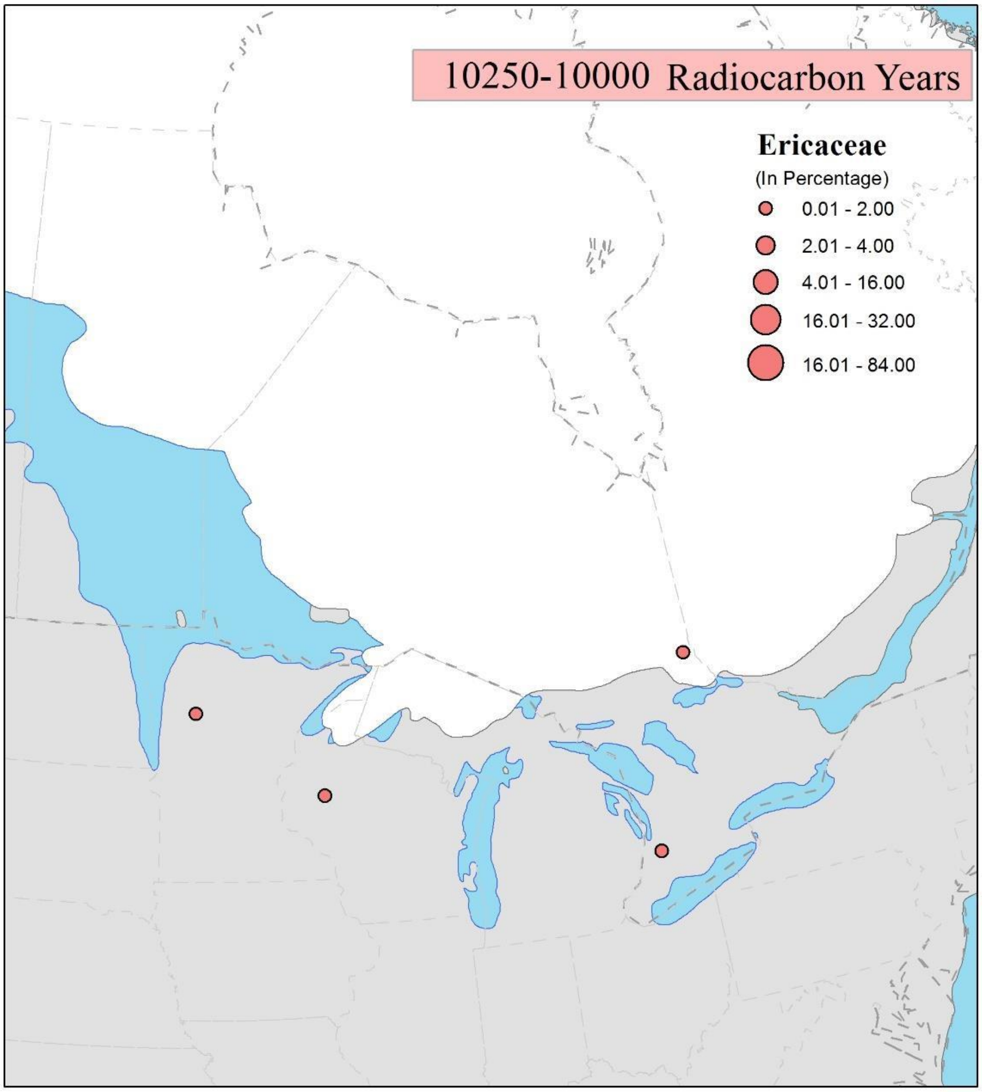

8750-8500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

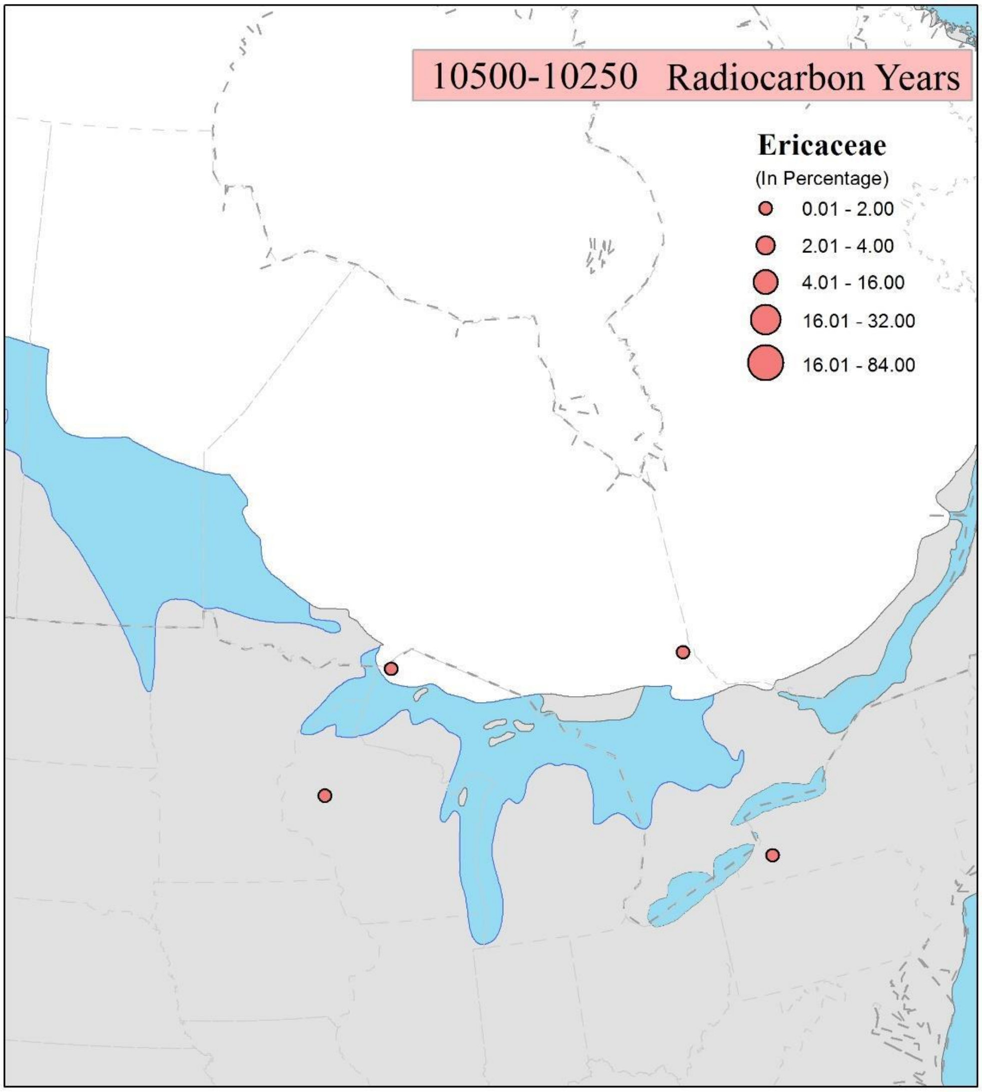

9000-8750 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

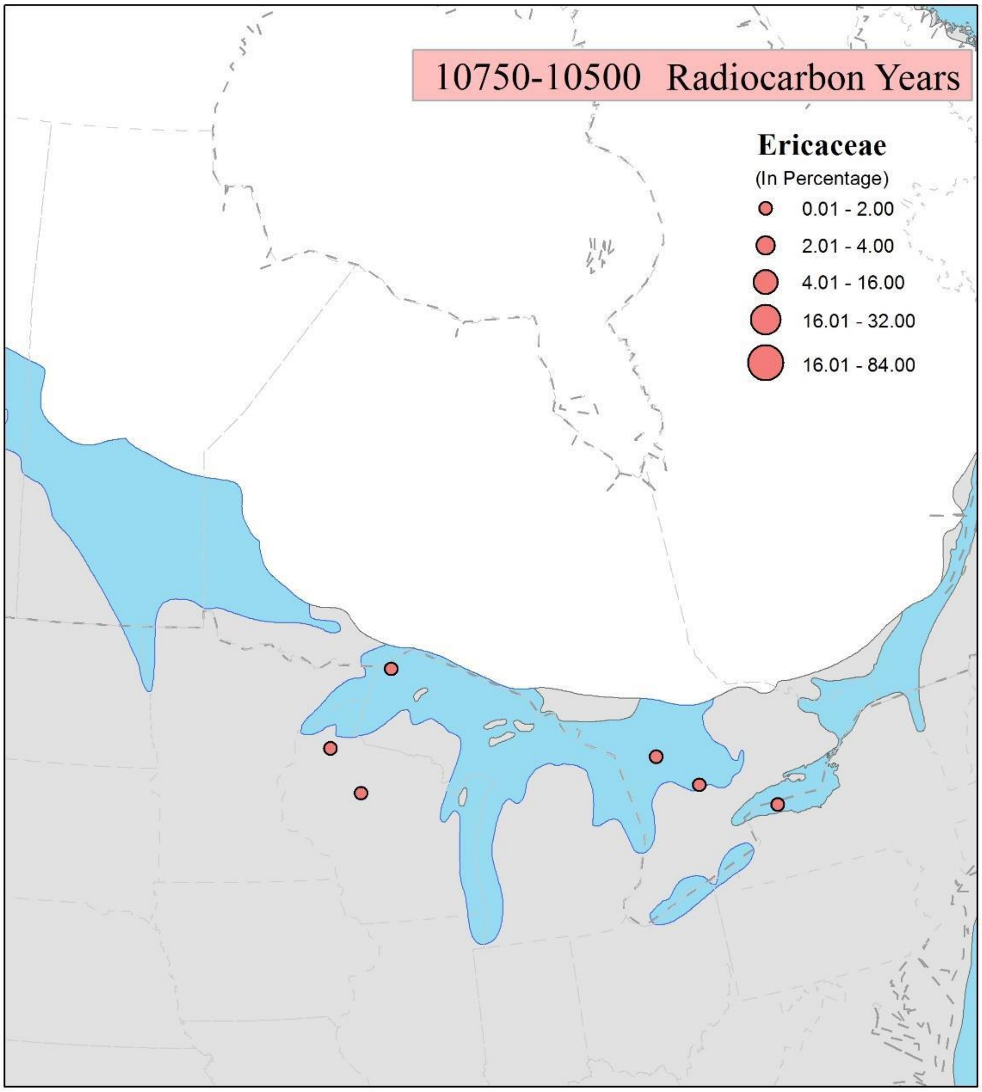


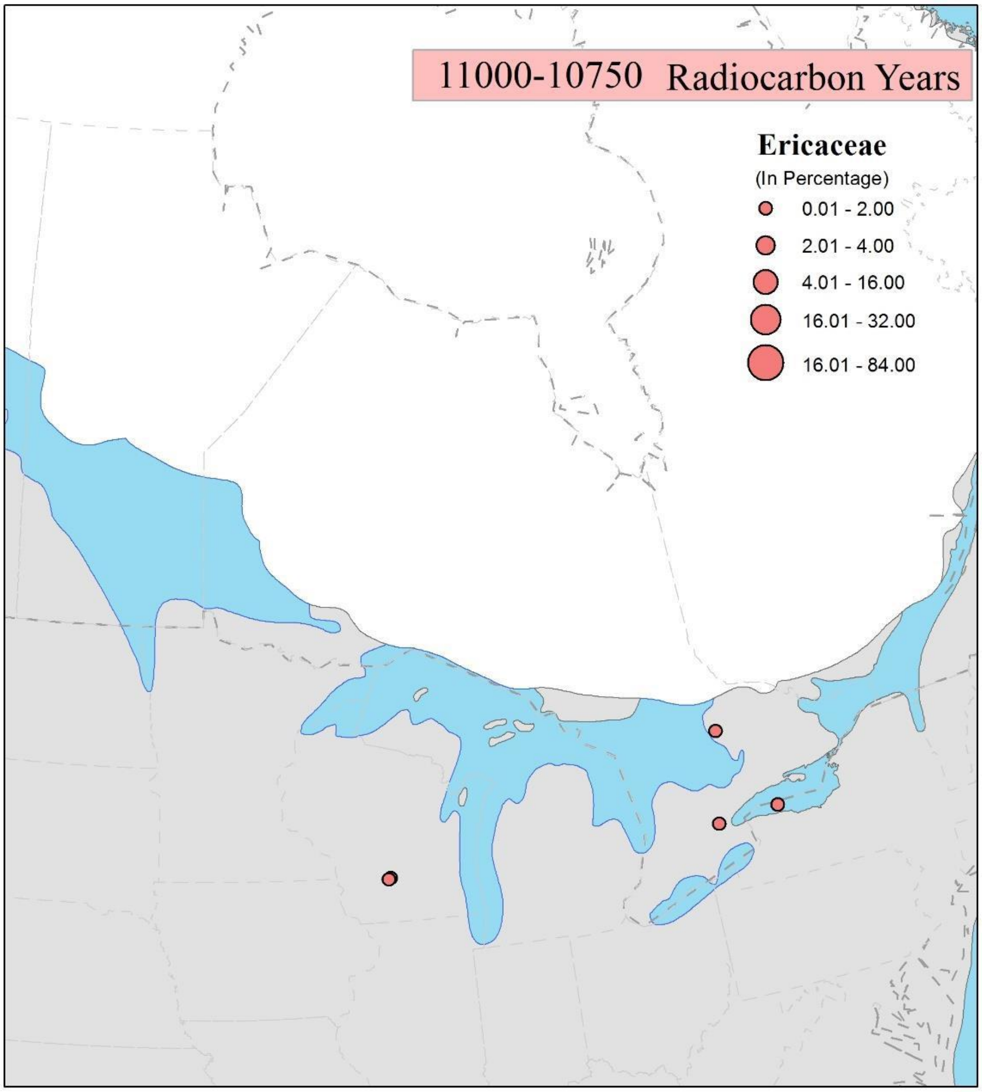
9500-9000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

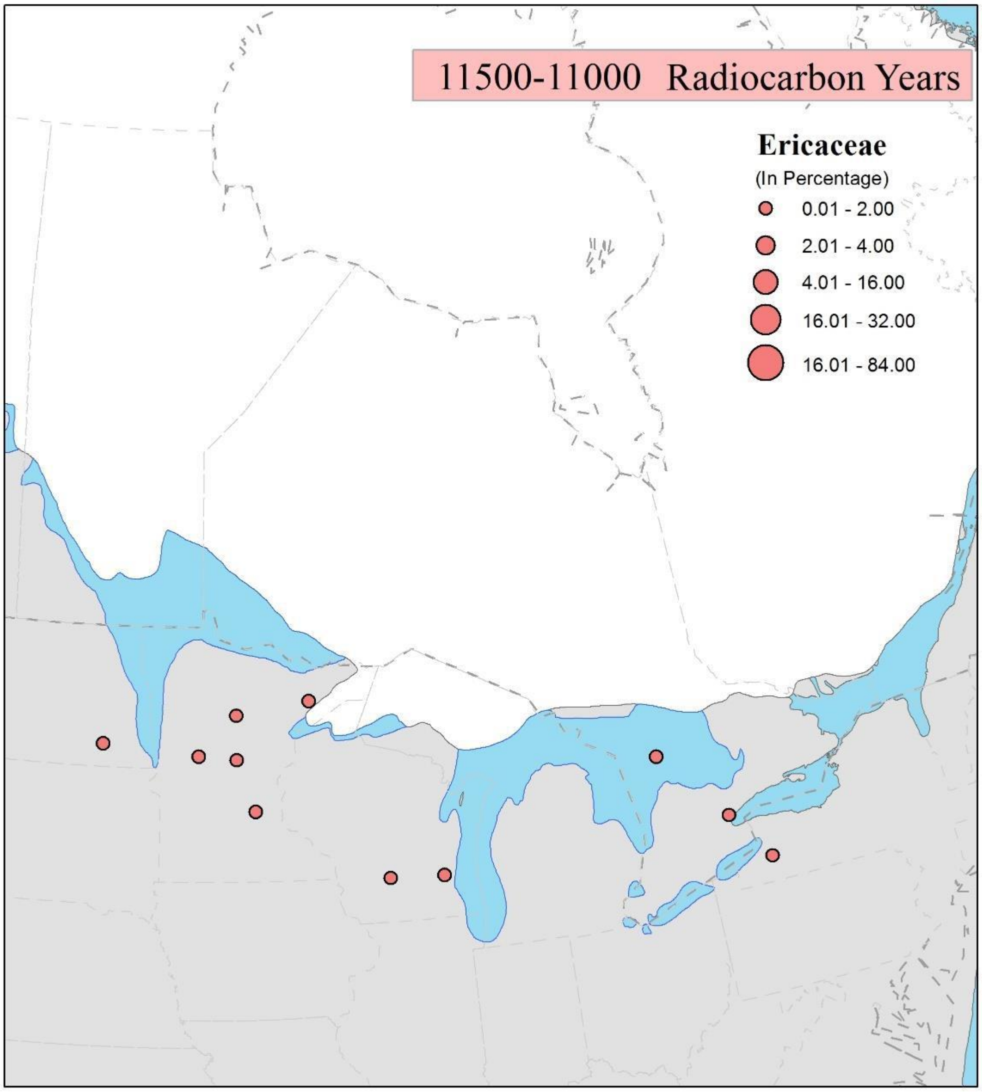

10000-9500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

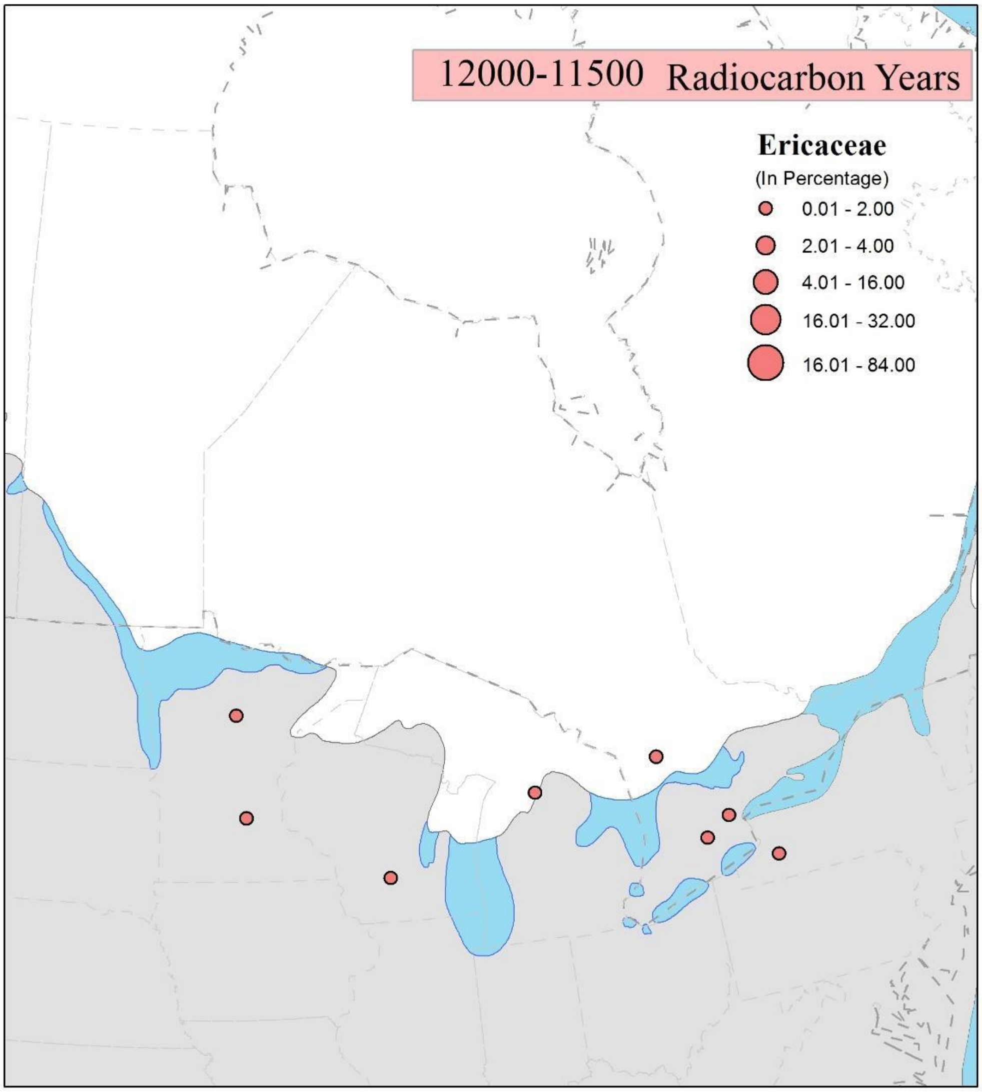

10250-10000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

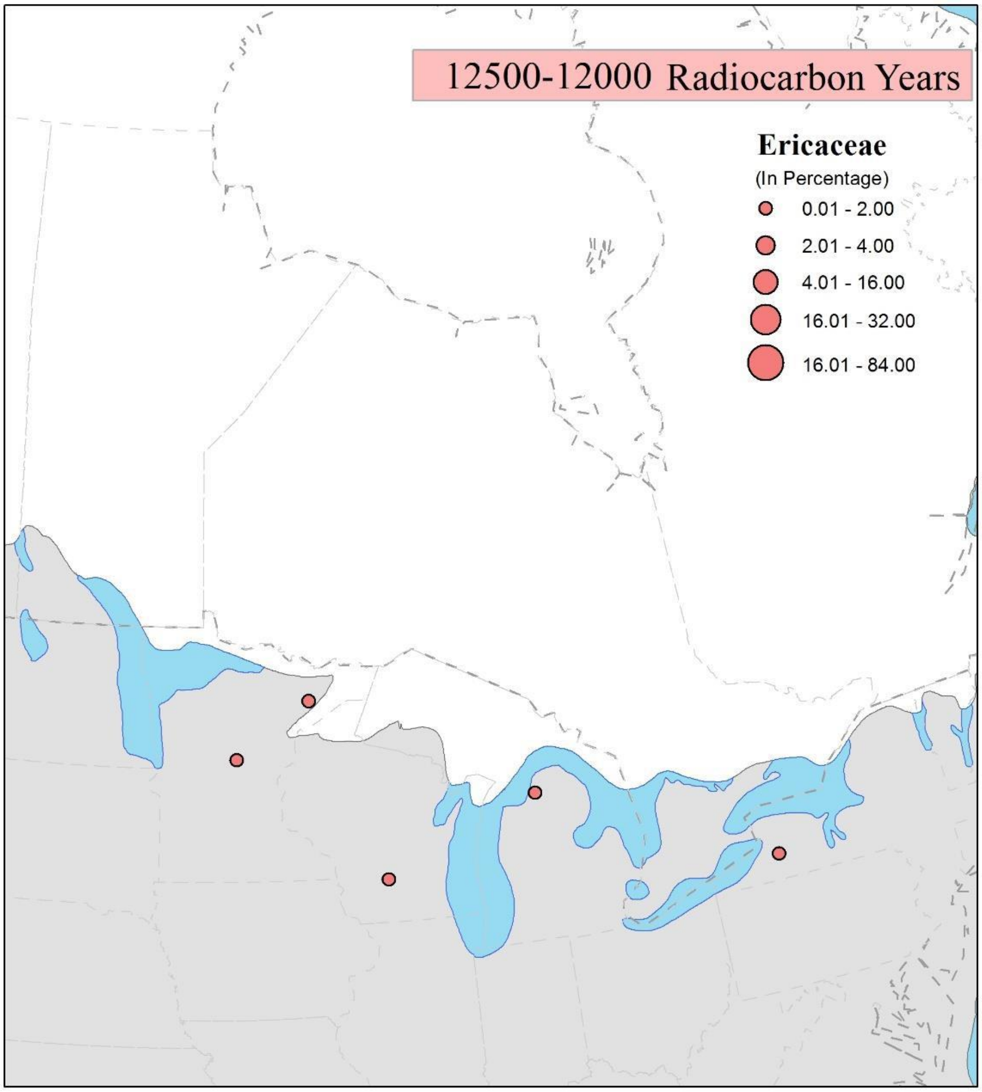

10500-10250 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

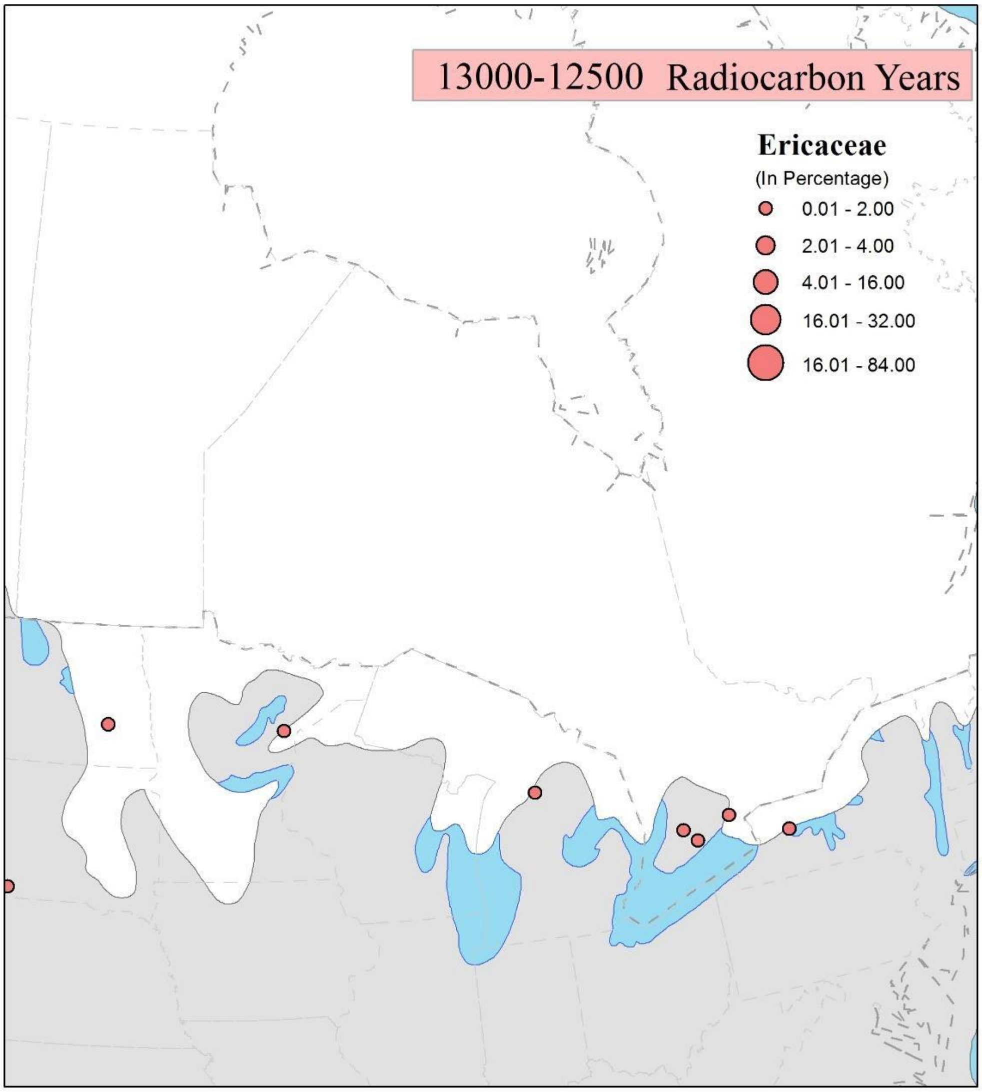

10750-10500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

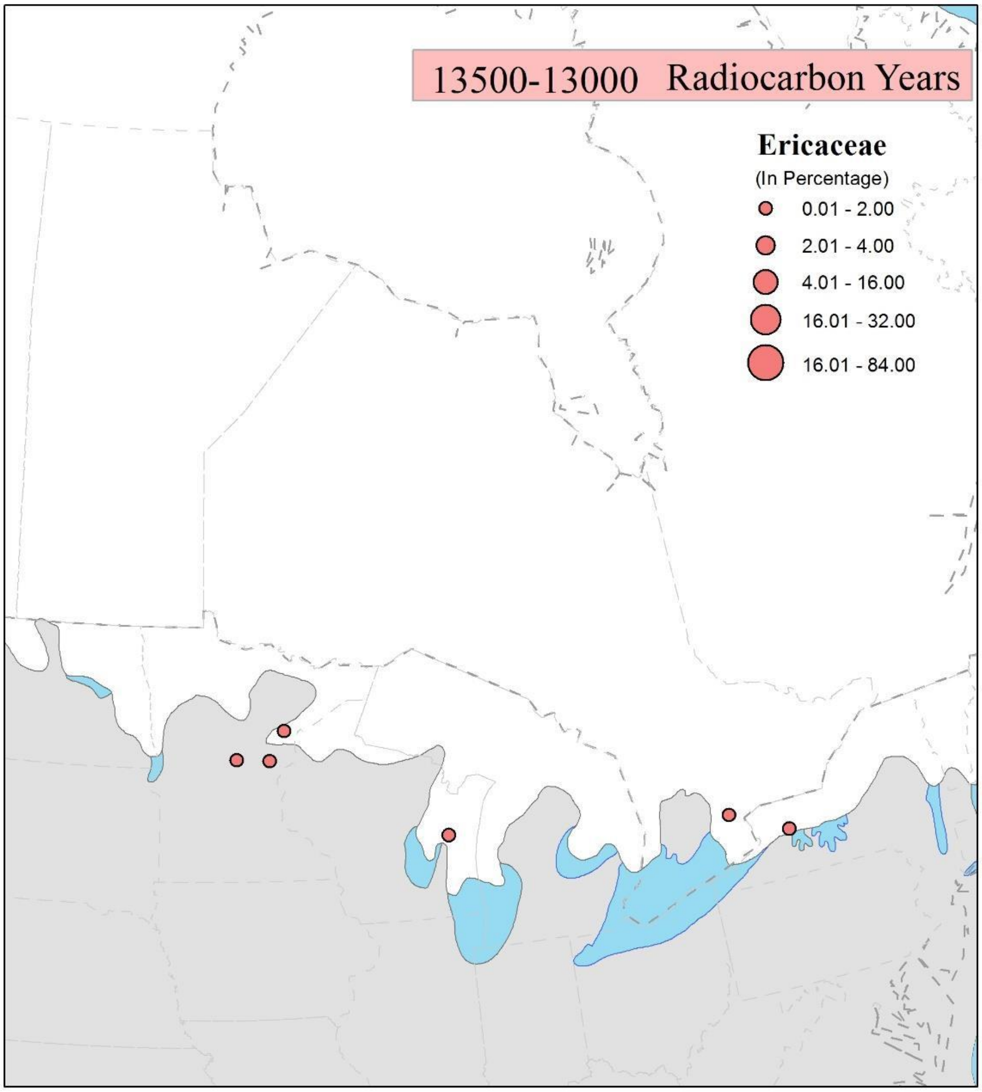

11000-10750 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

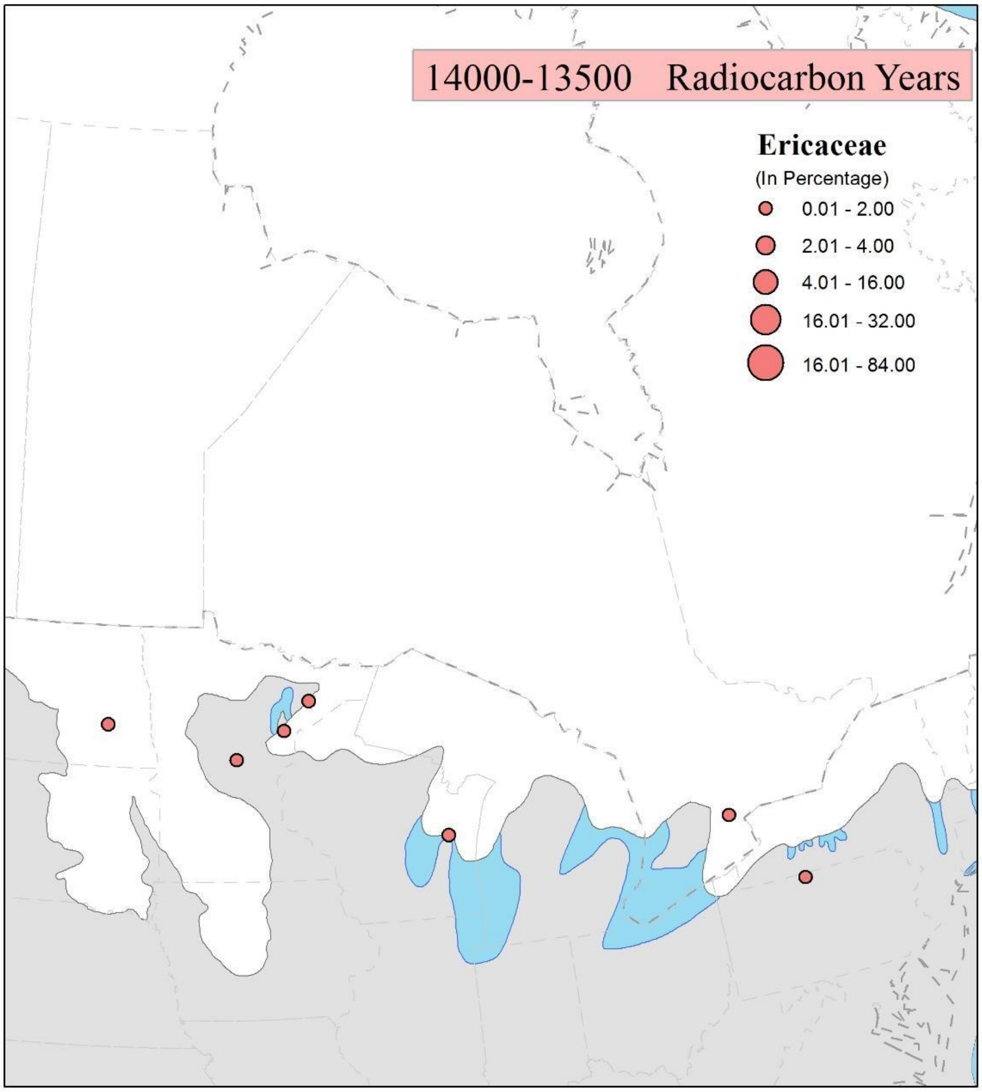

11500-11000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

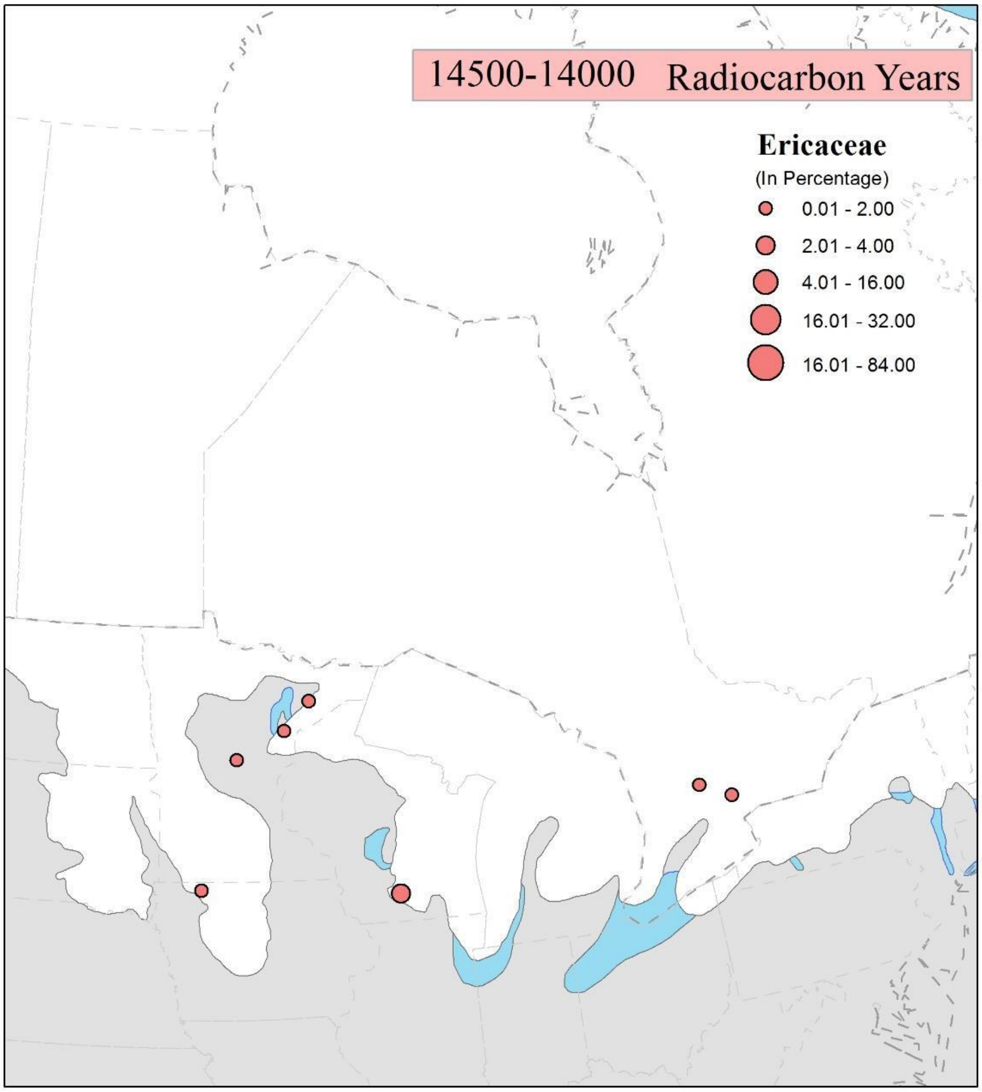

12000-11500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

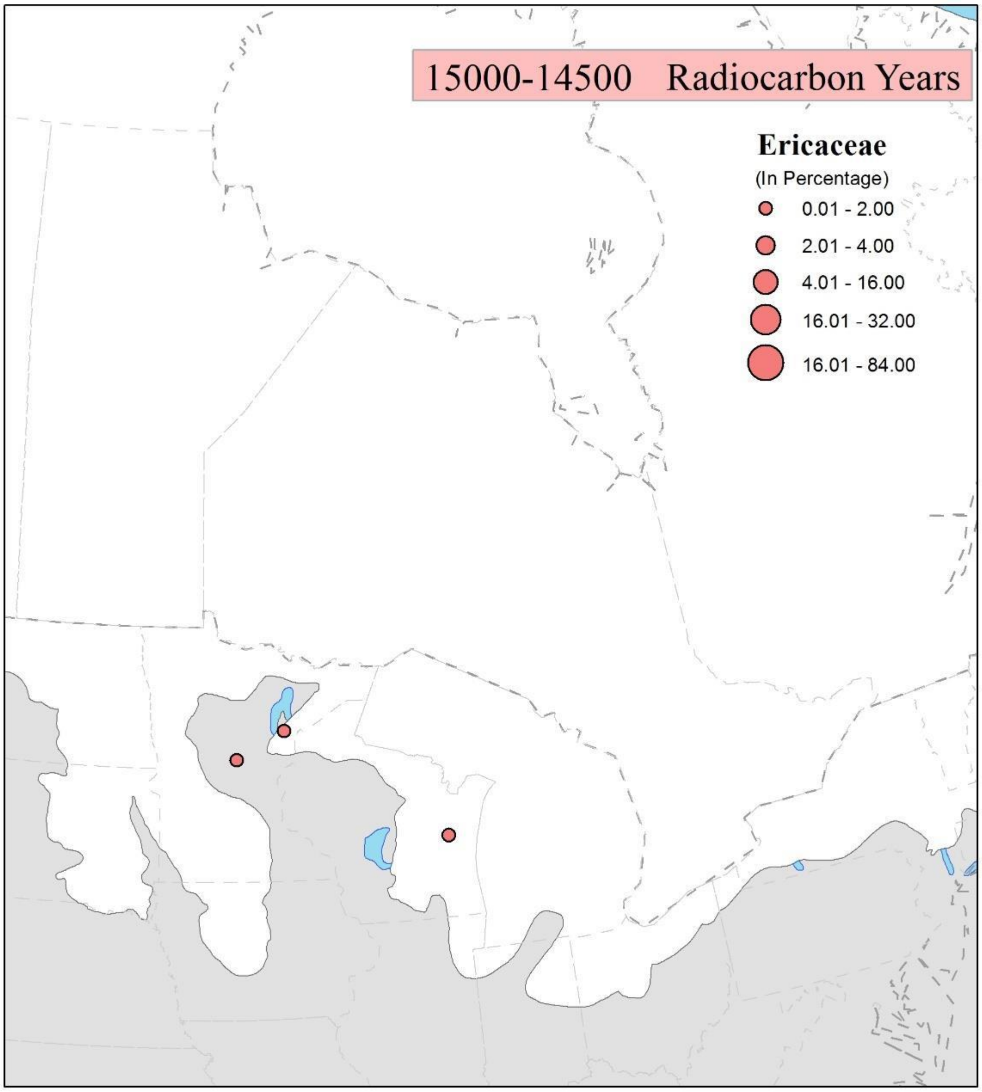

12500-12000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

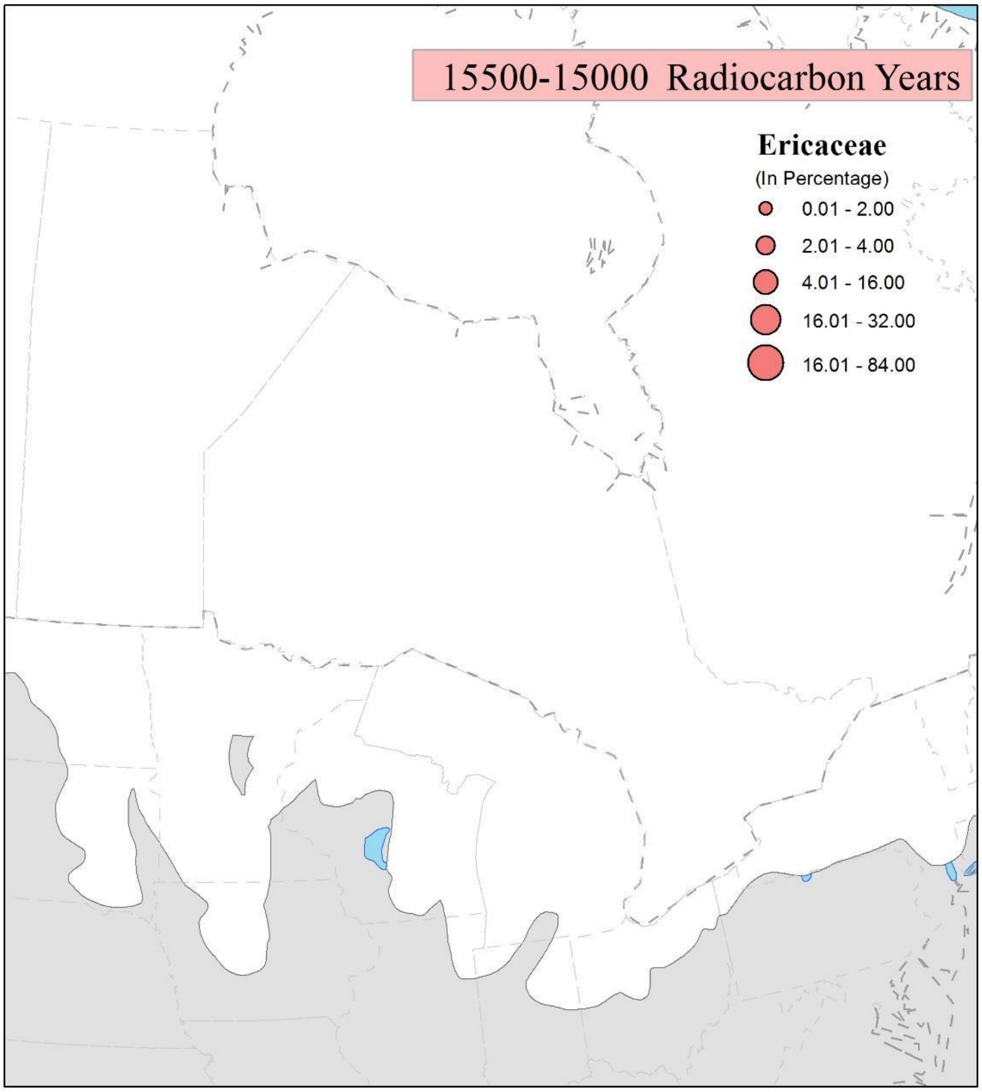

13000-12500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

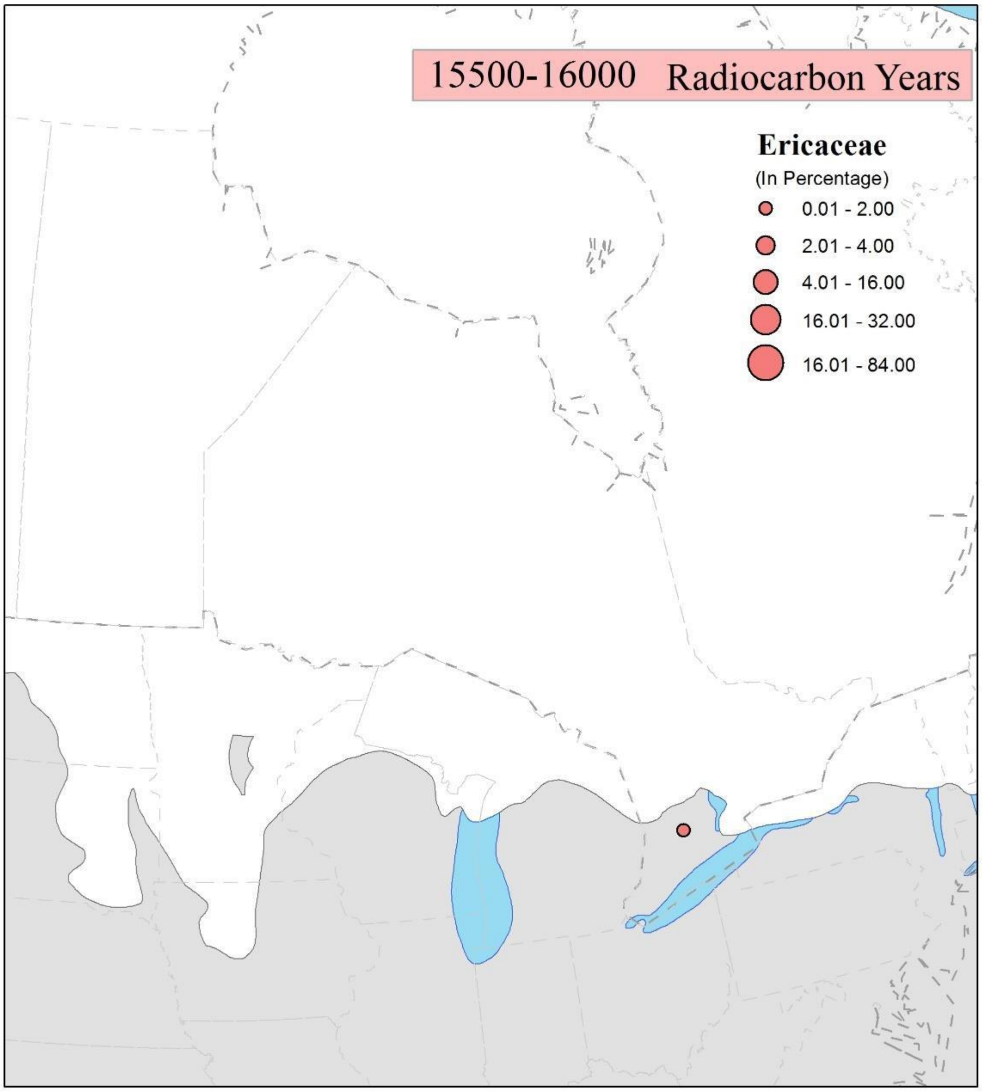

13500-13000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00


14000-13500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00


14500-14000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

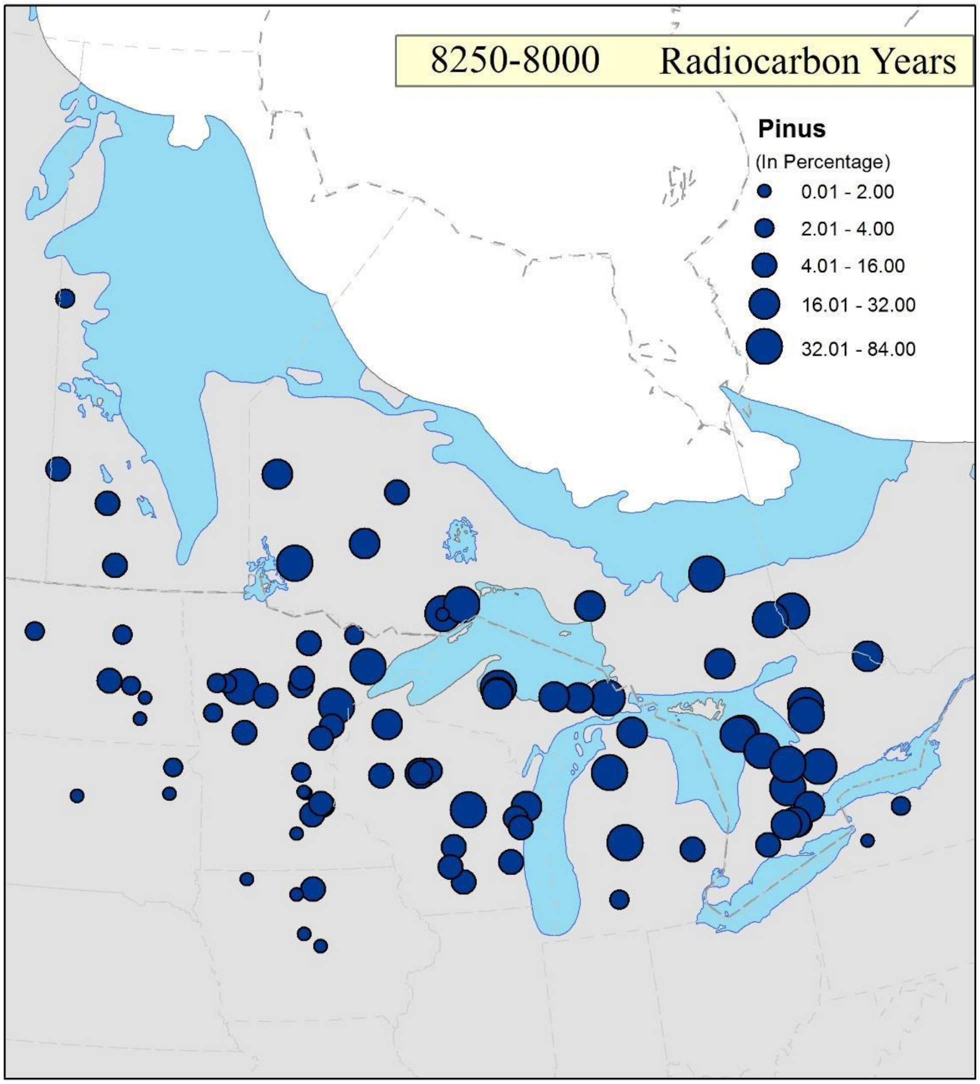

15000-14500 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

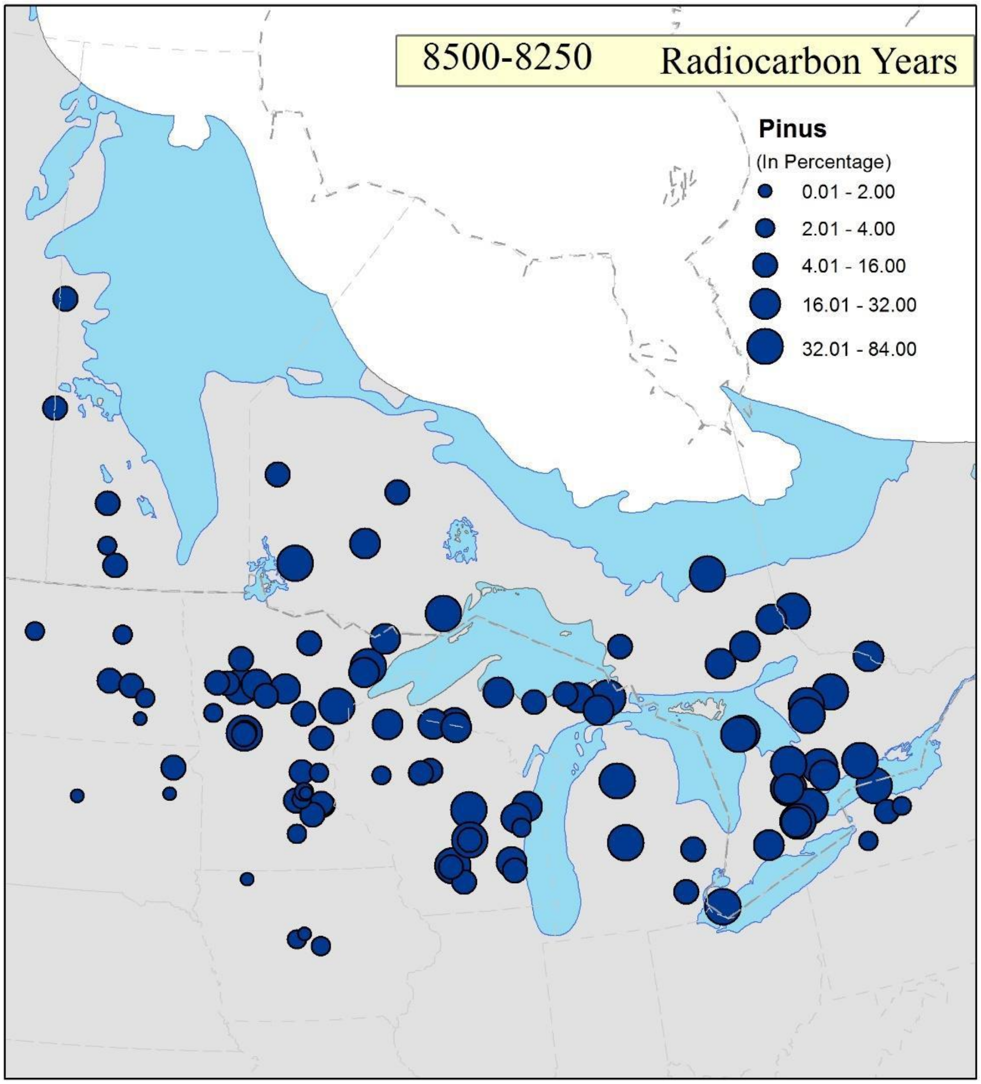

15500-15000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

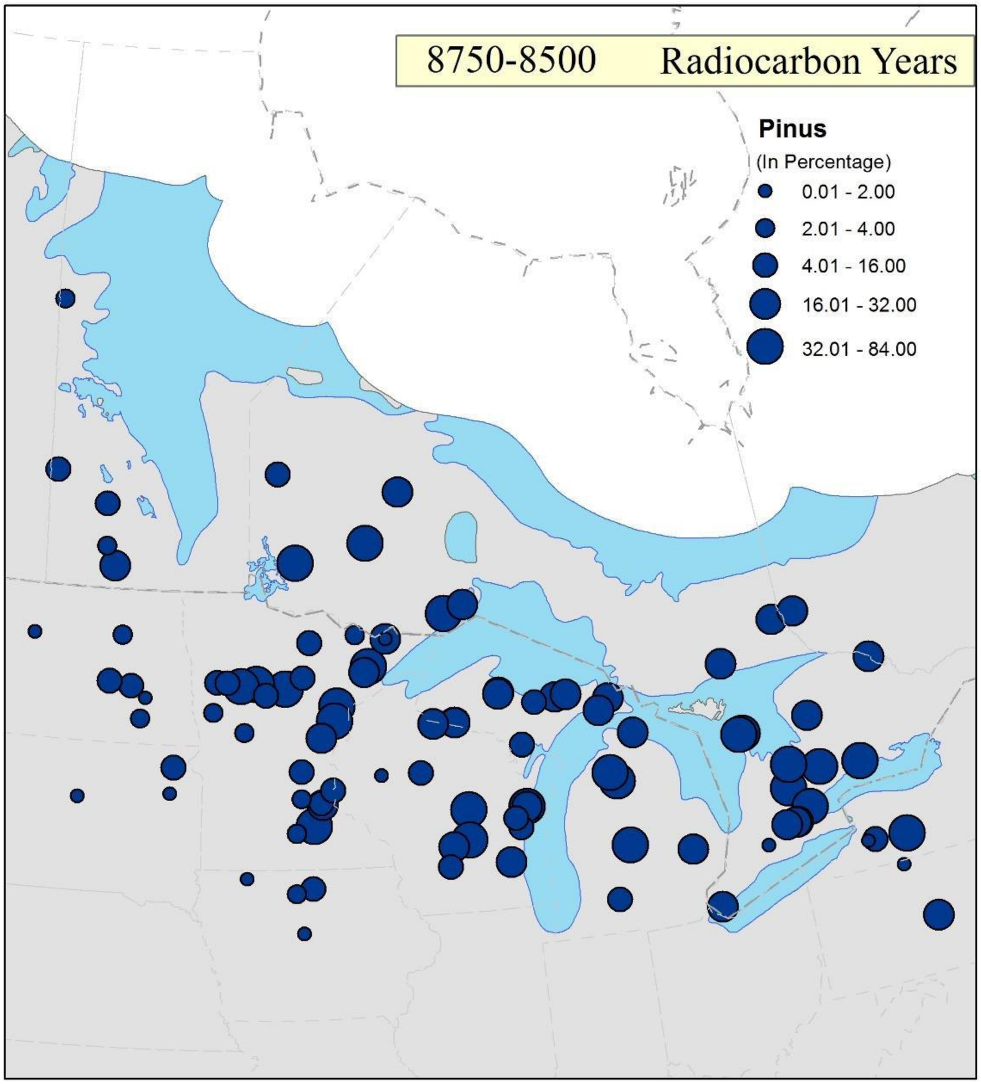

15500-16000 Radiocarbon Years
Ericaceae
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
16.01 - 84.00

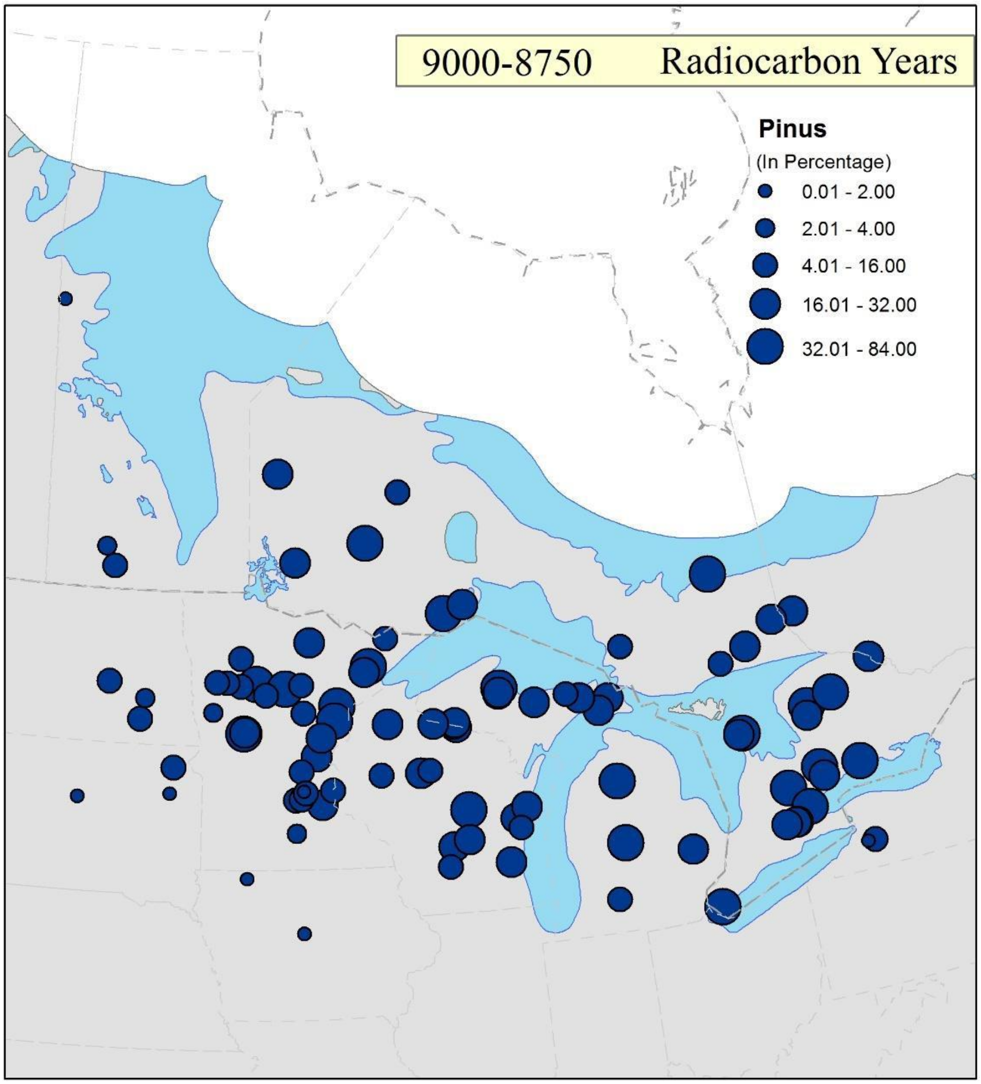
Appendix VI

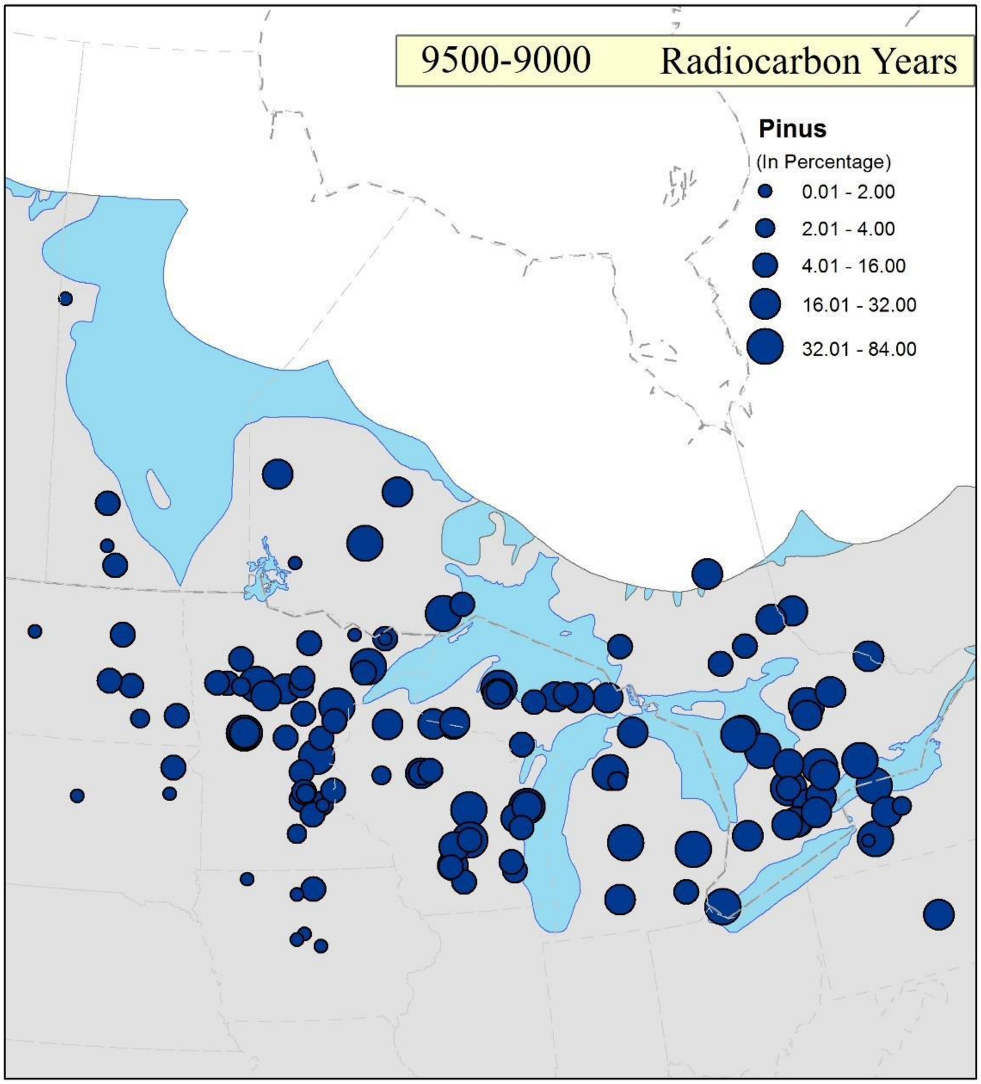
Pollen abundance of *Pinus*

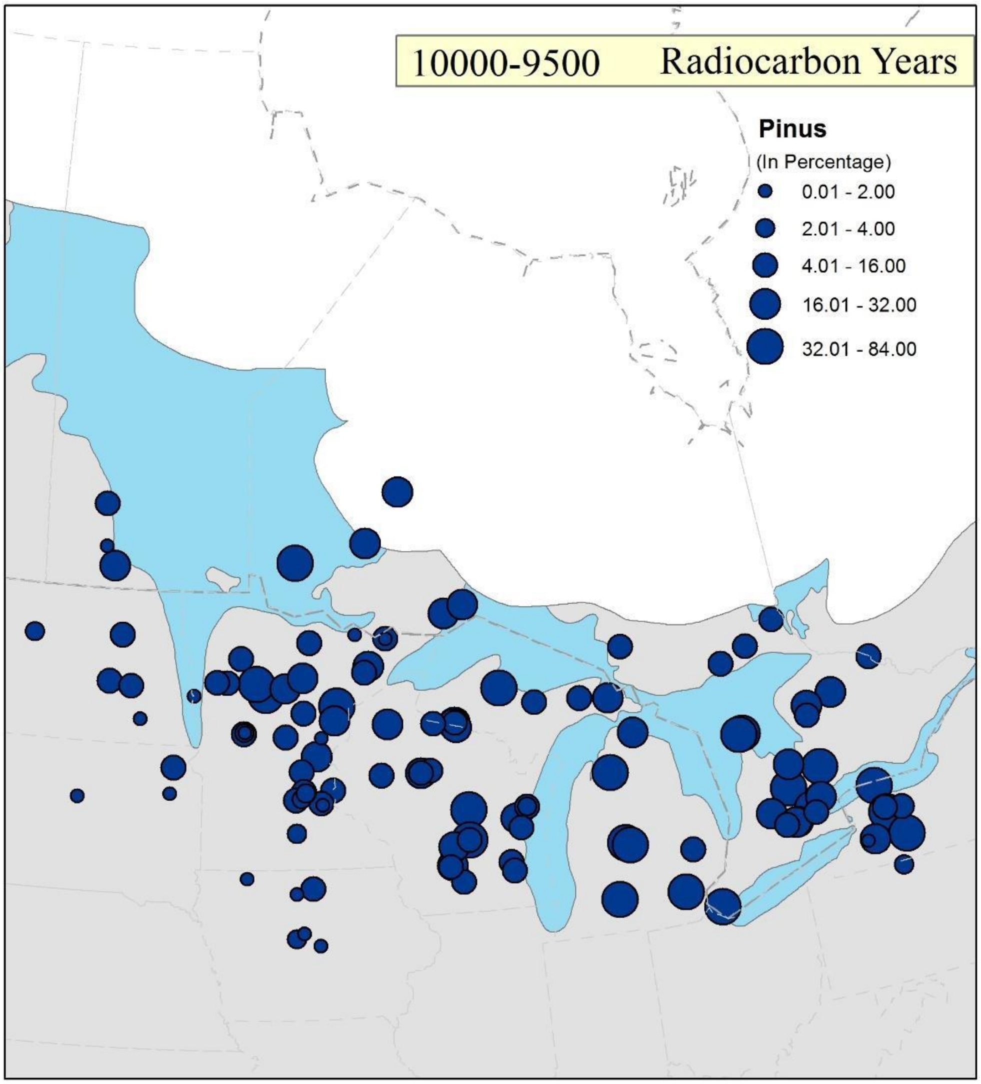

8250-8000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

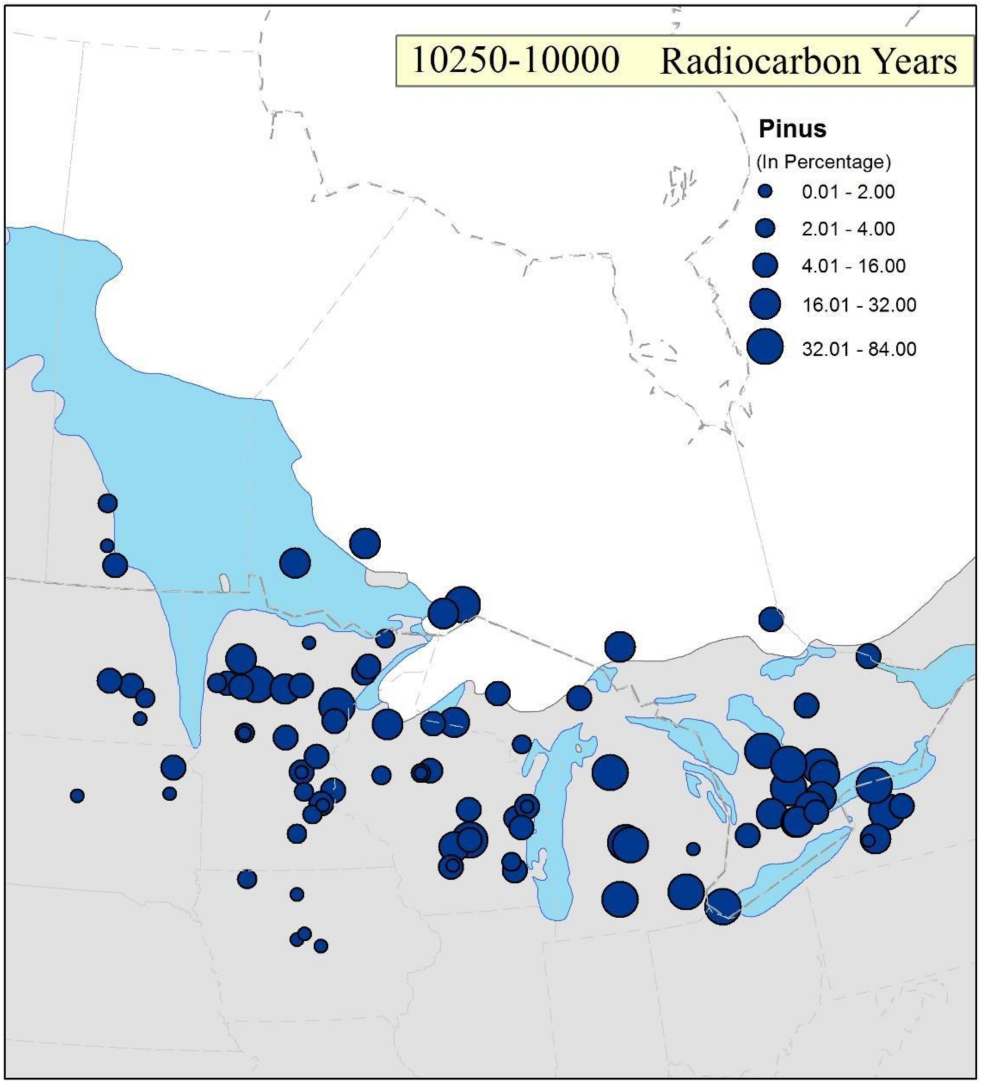

8500-8250 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


8750-8500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

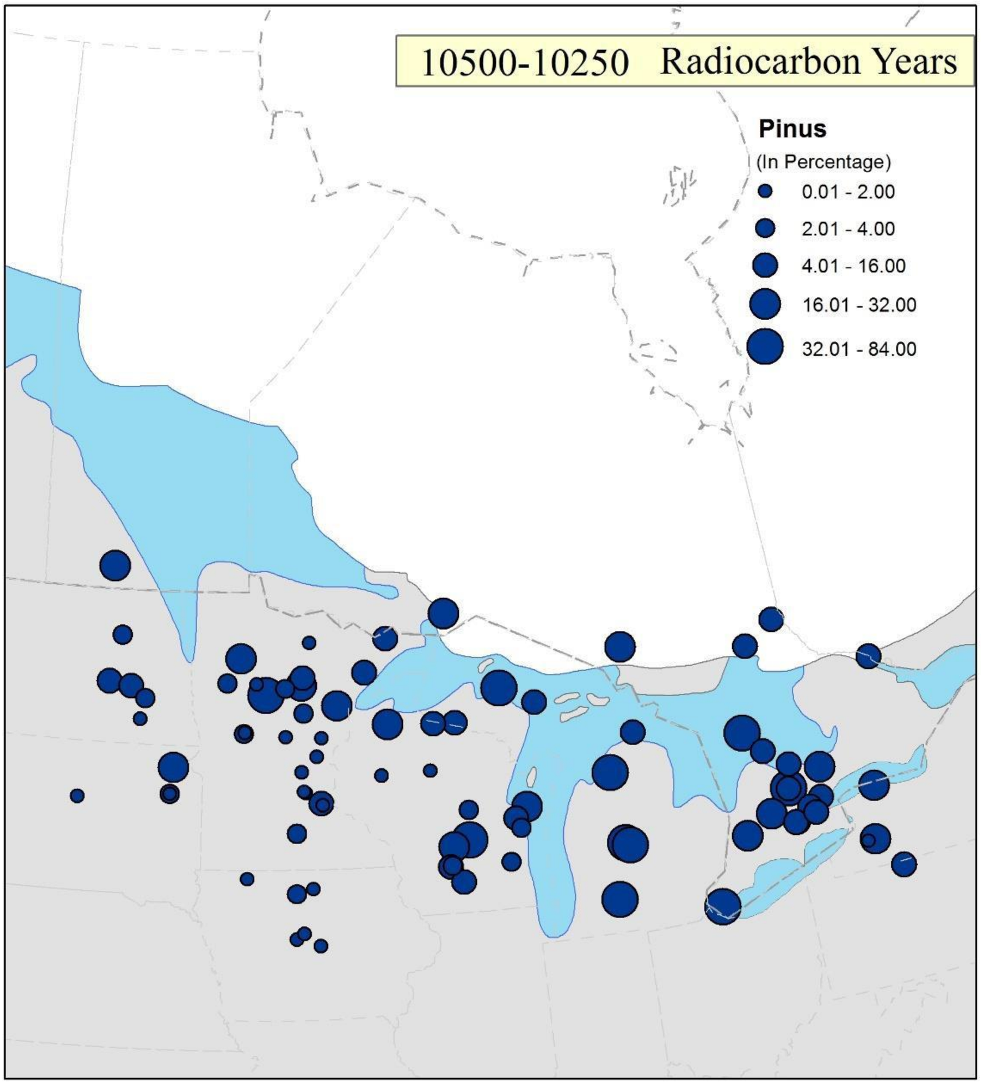

9000-8750 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

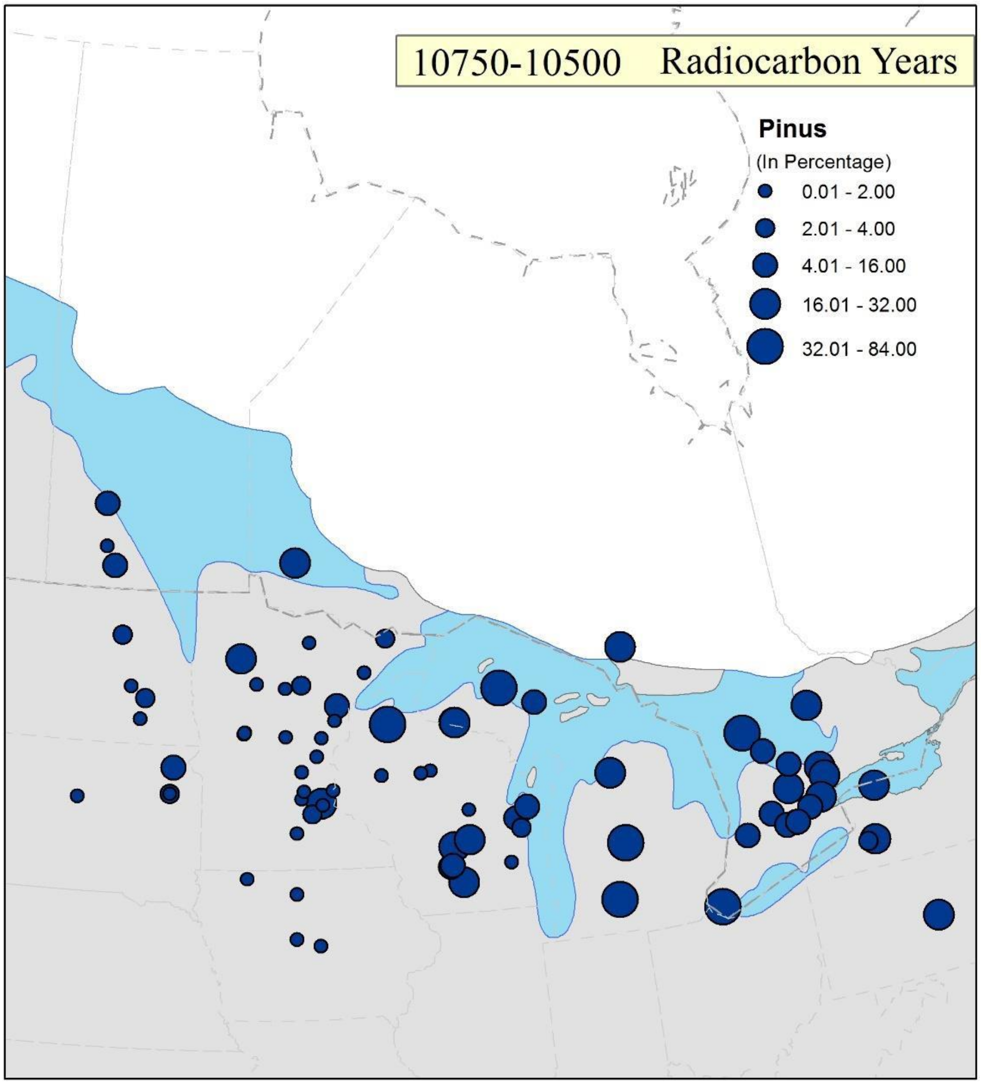

9500-9000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

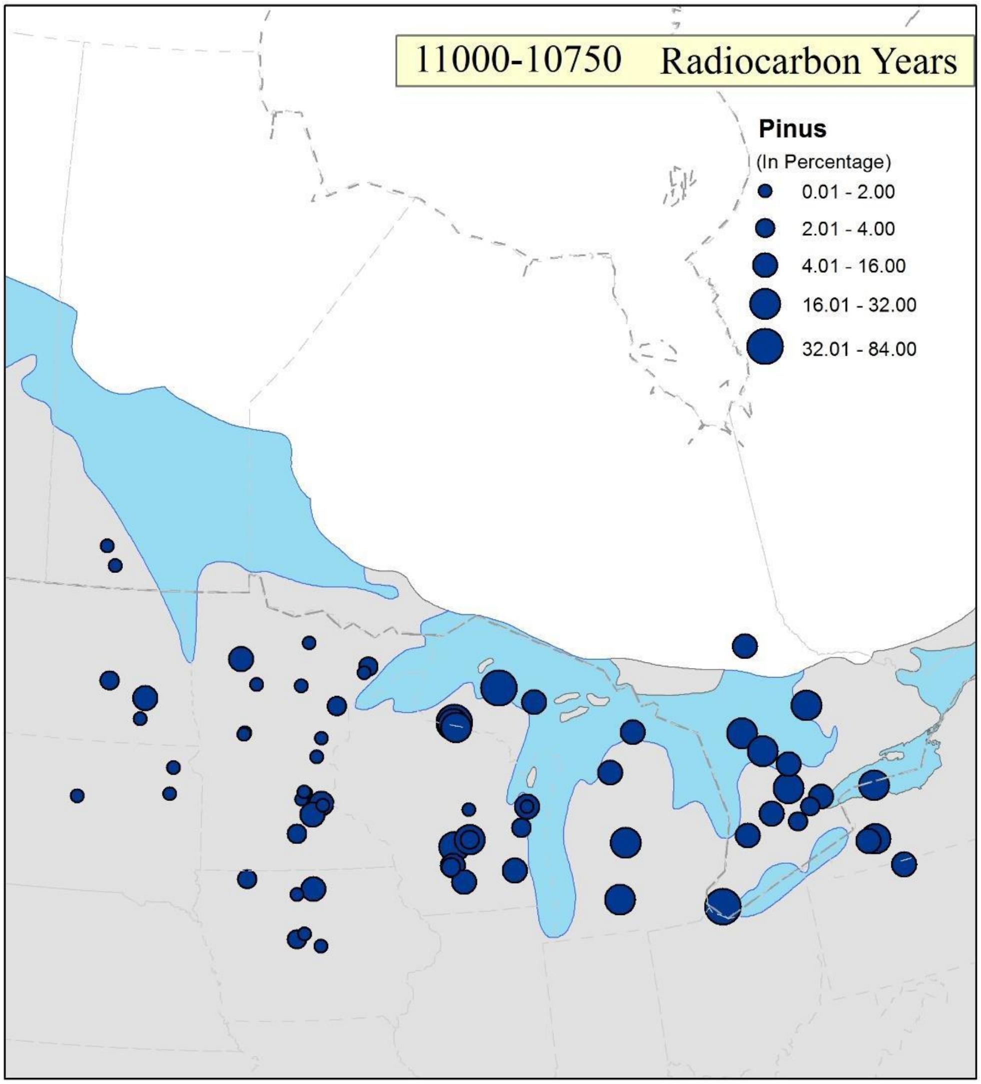

10000-9500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

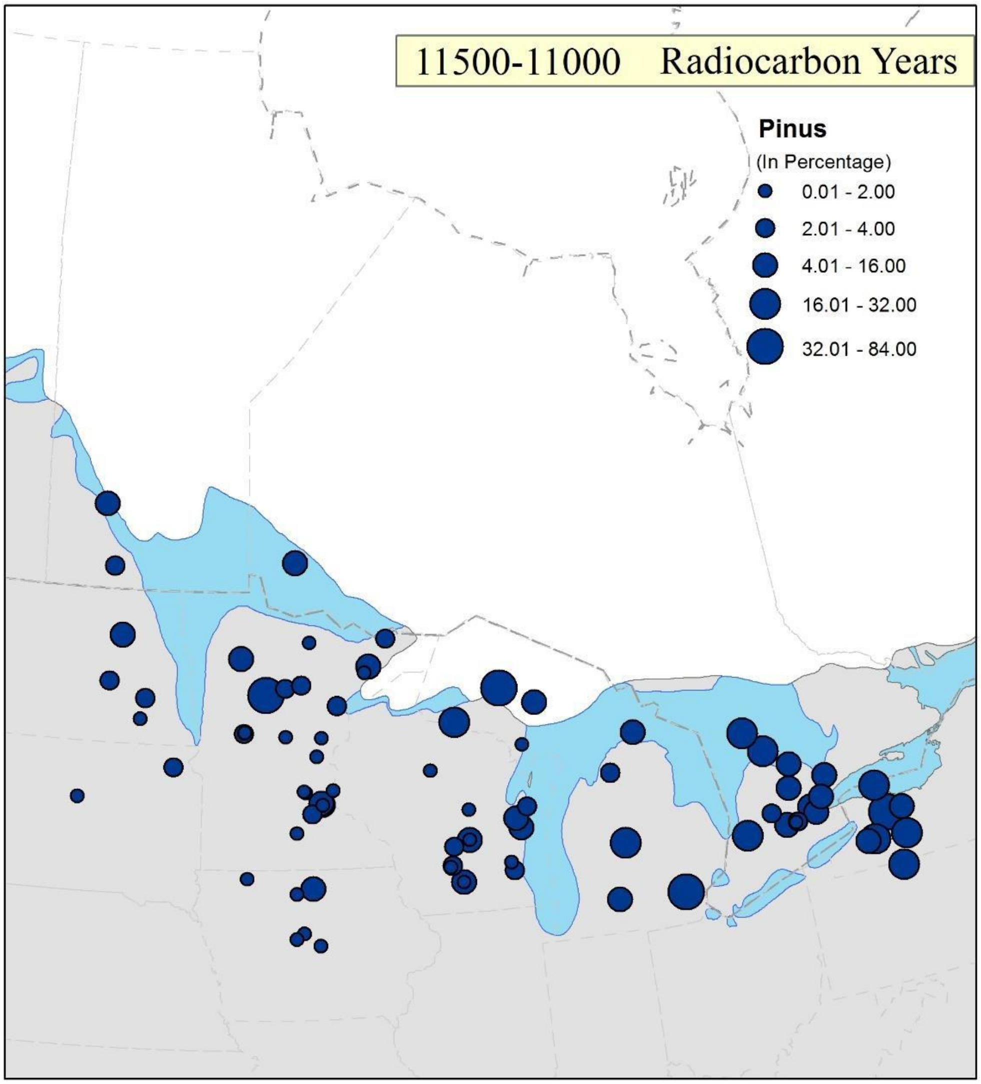


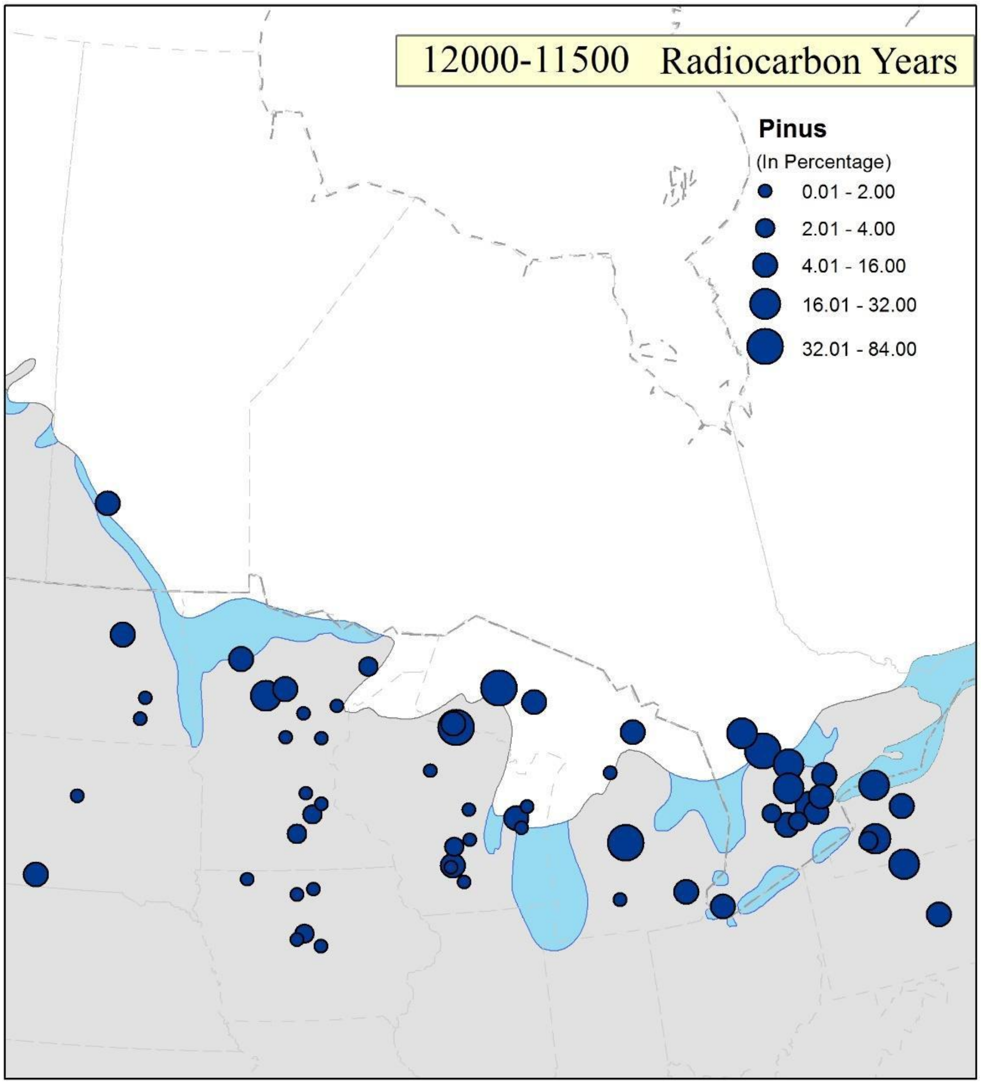
10250-10000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

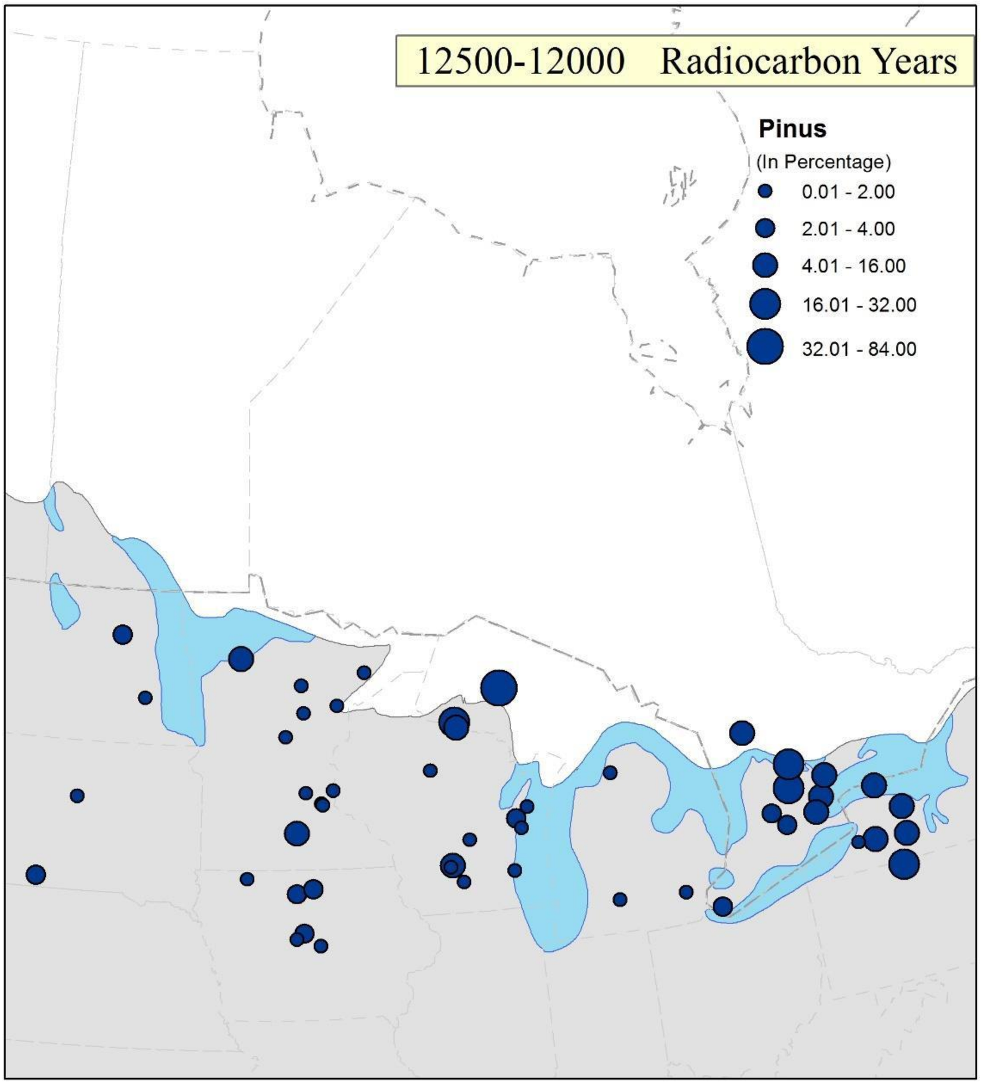

10500-10250 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

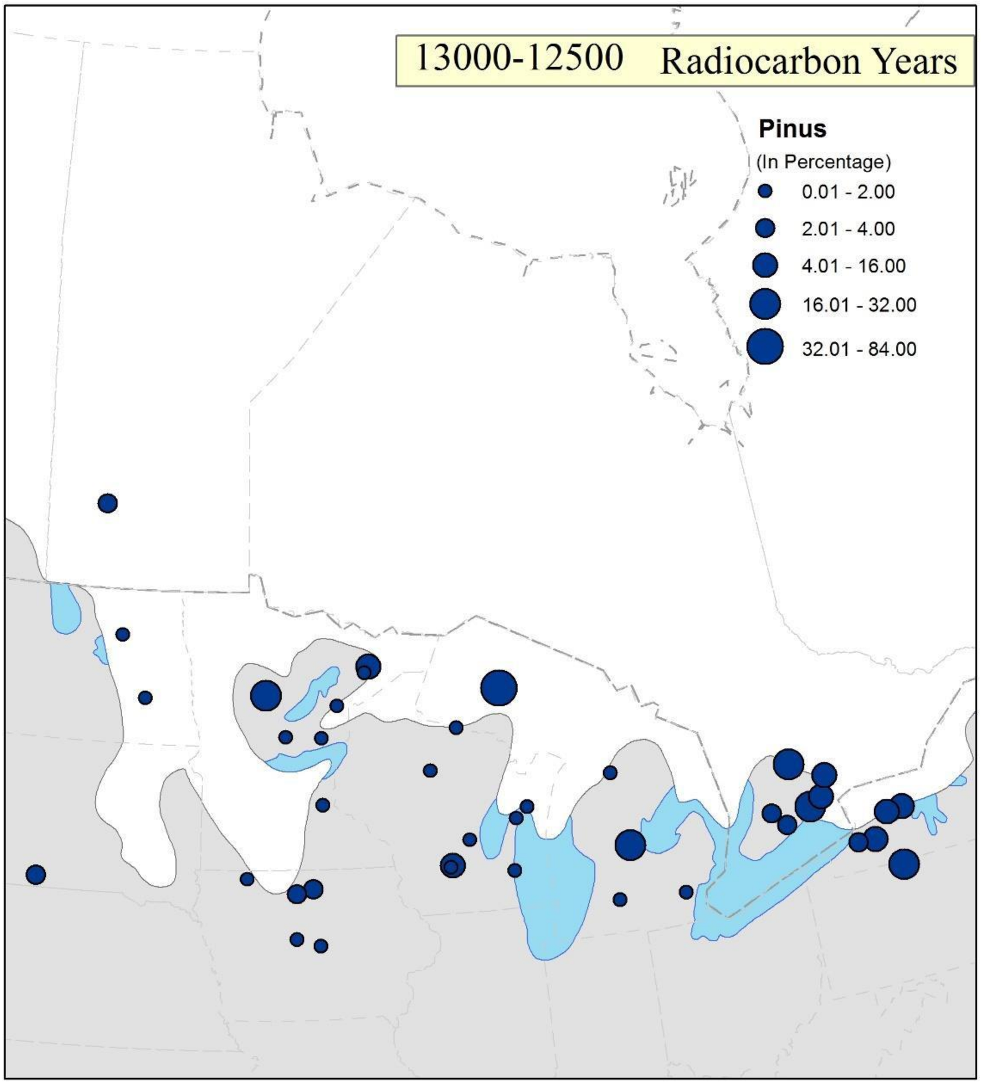

10750-10500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

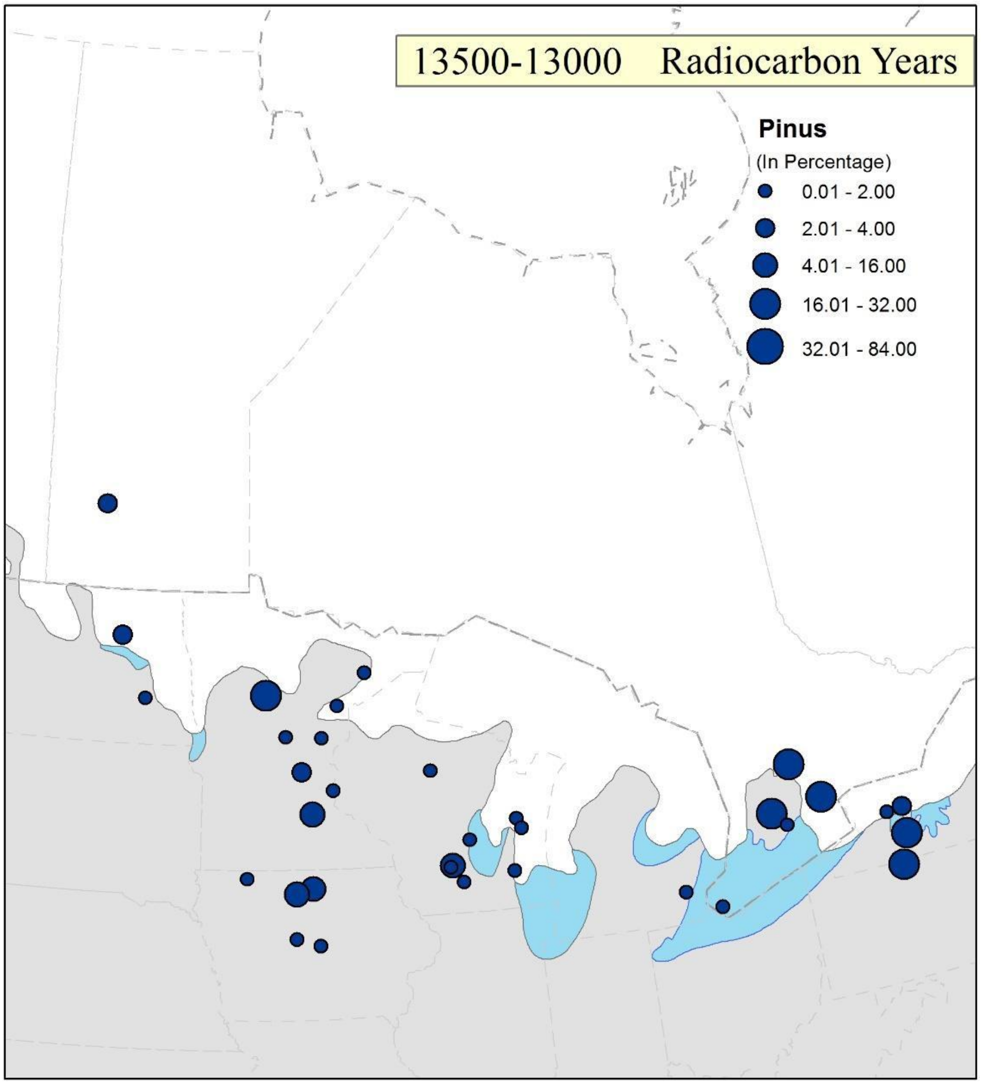

11000-10750 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

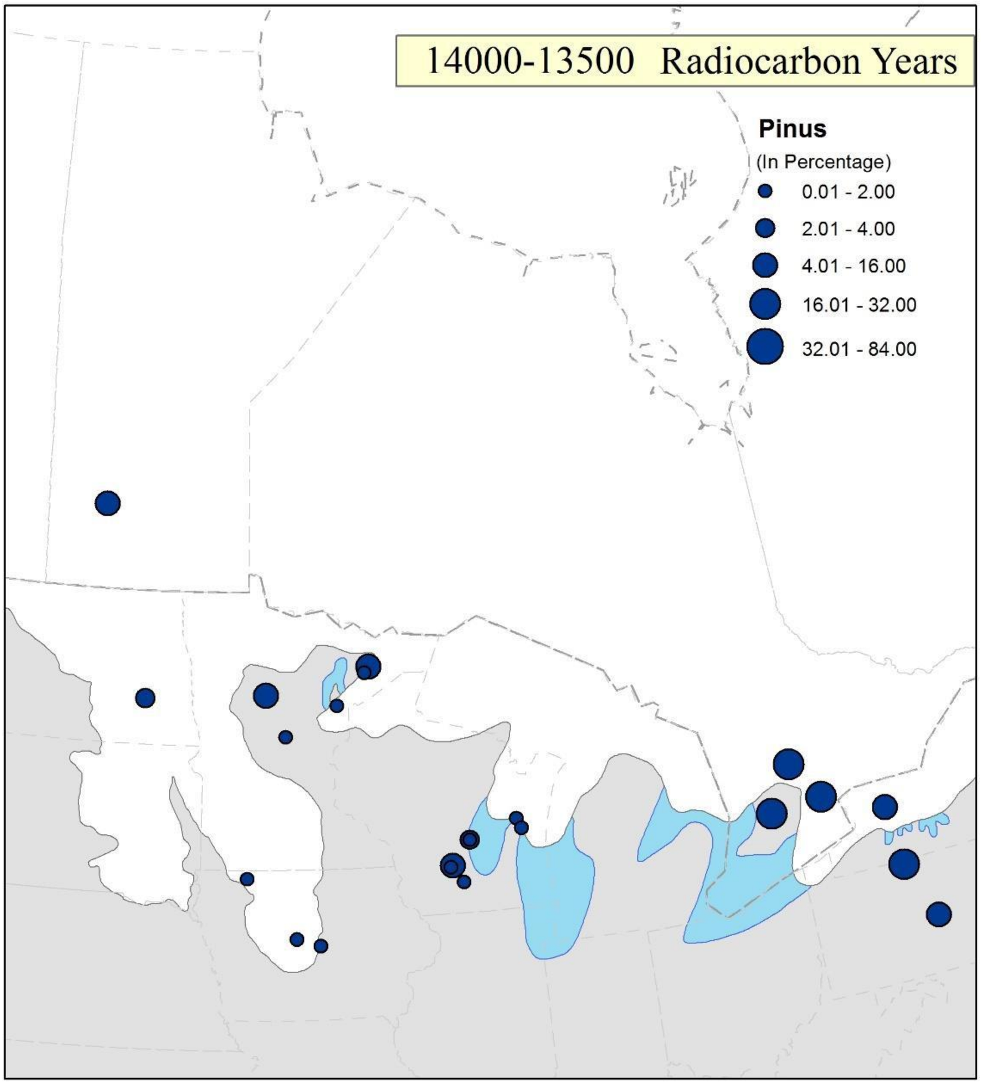

11500-11000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

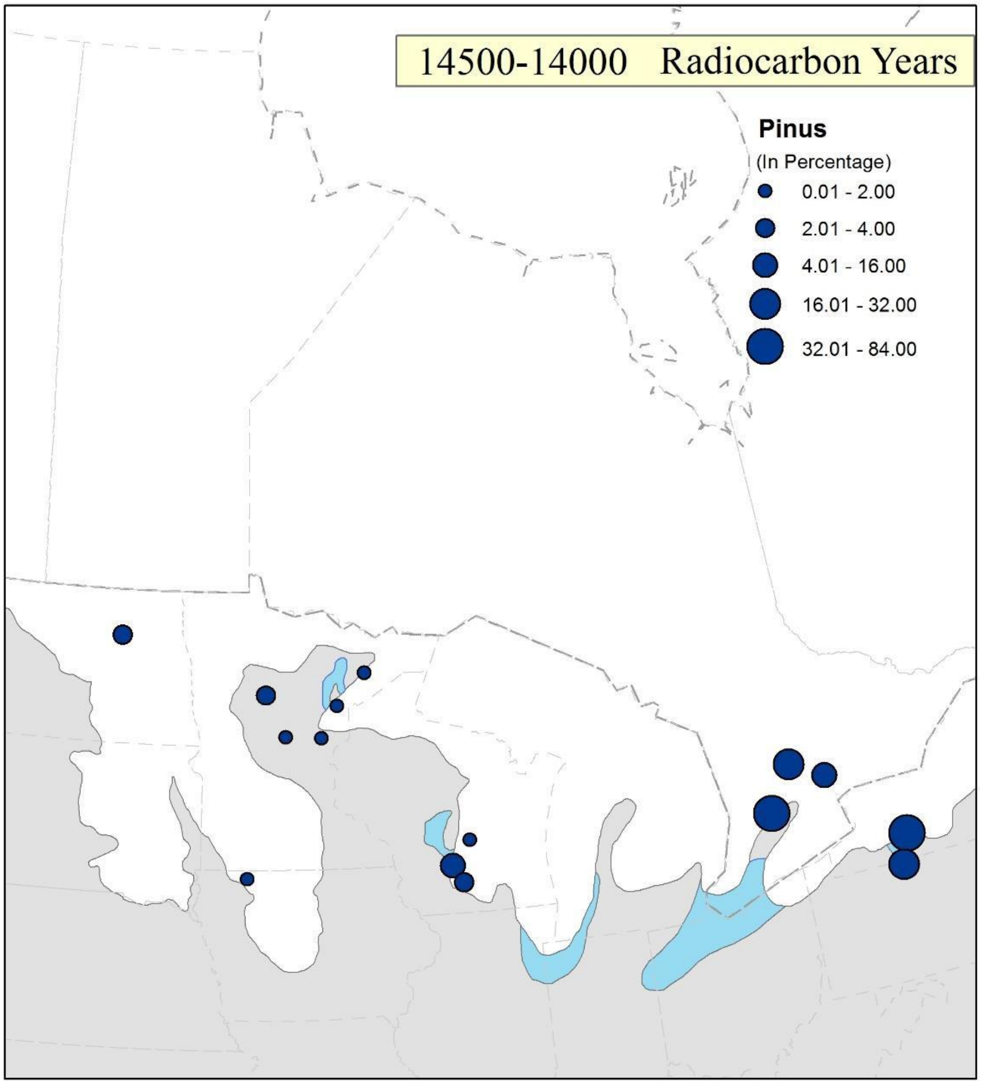

12000-11500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

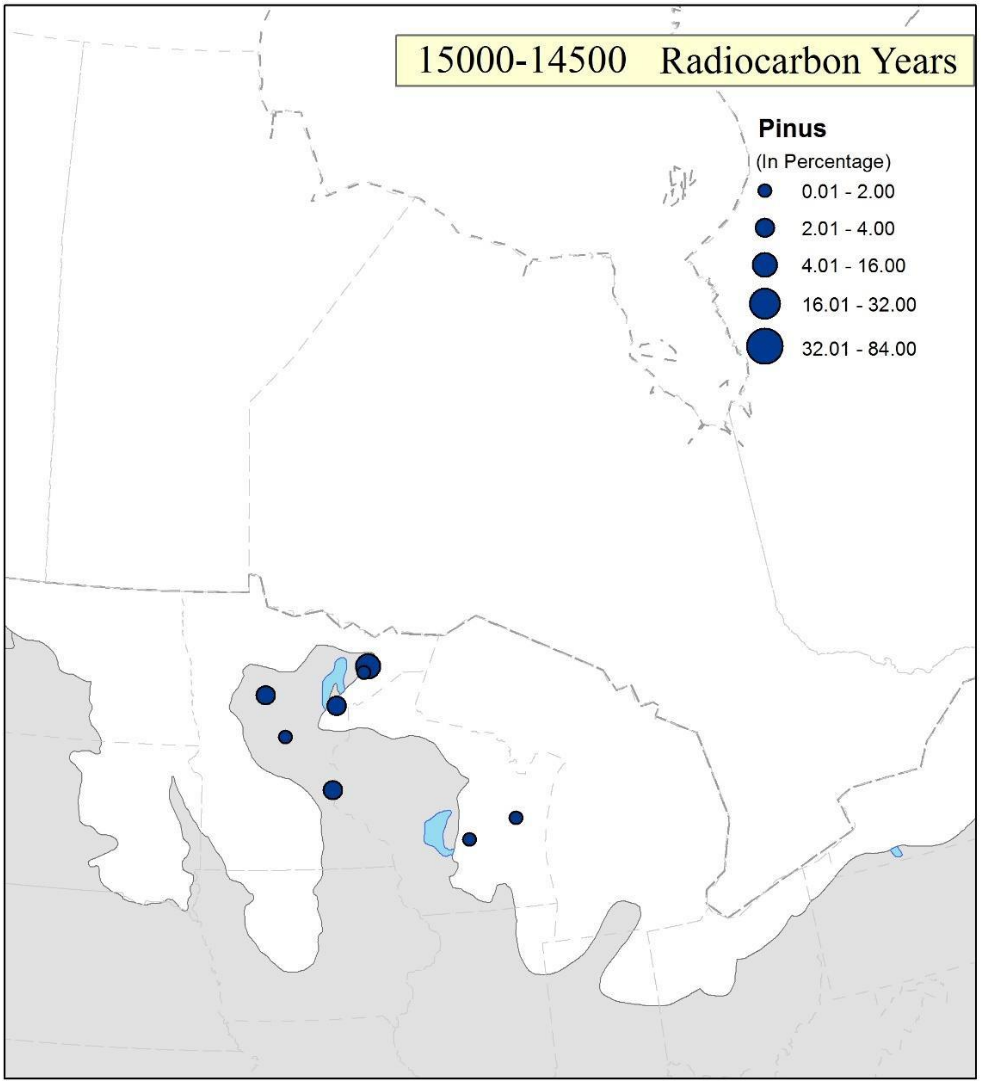

12500-12000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

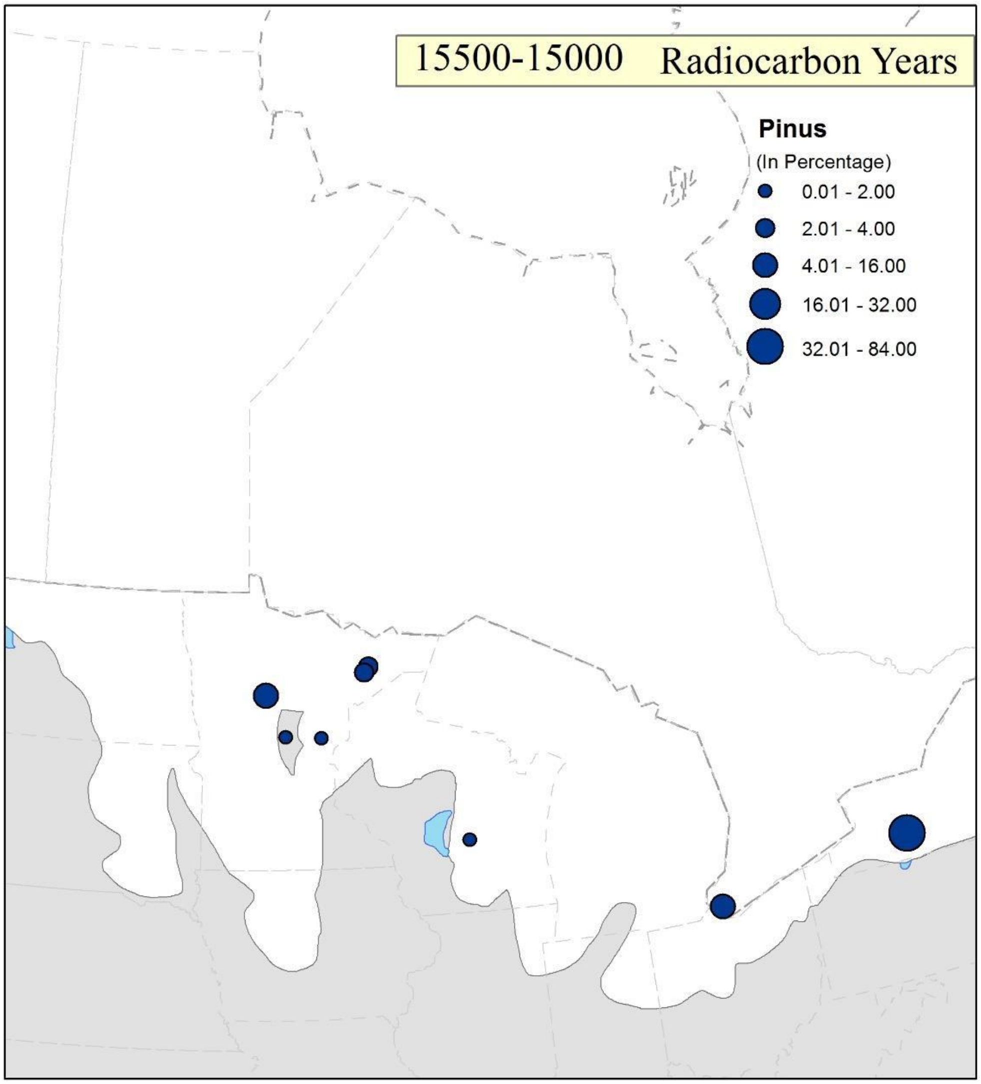

13000-12500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

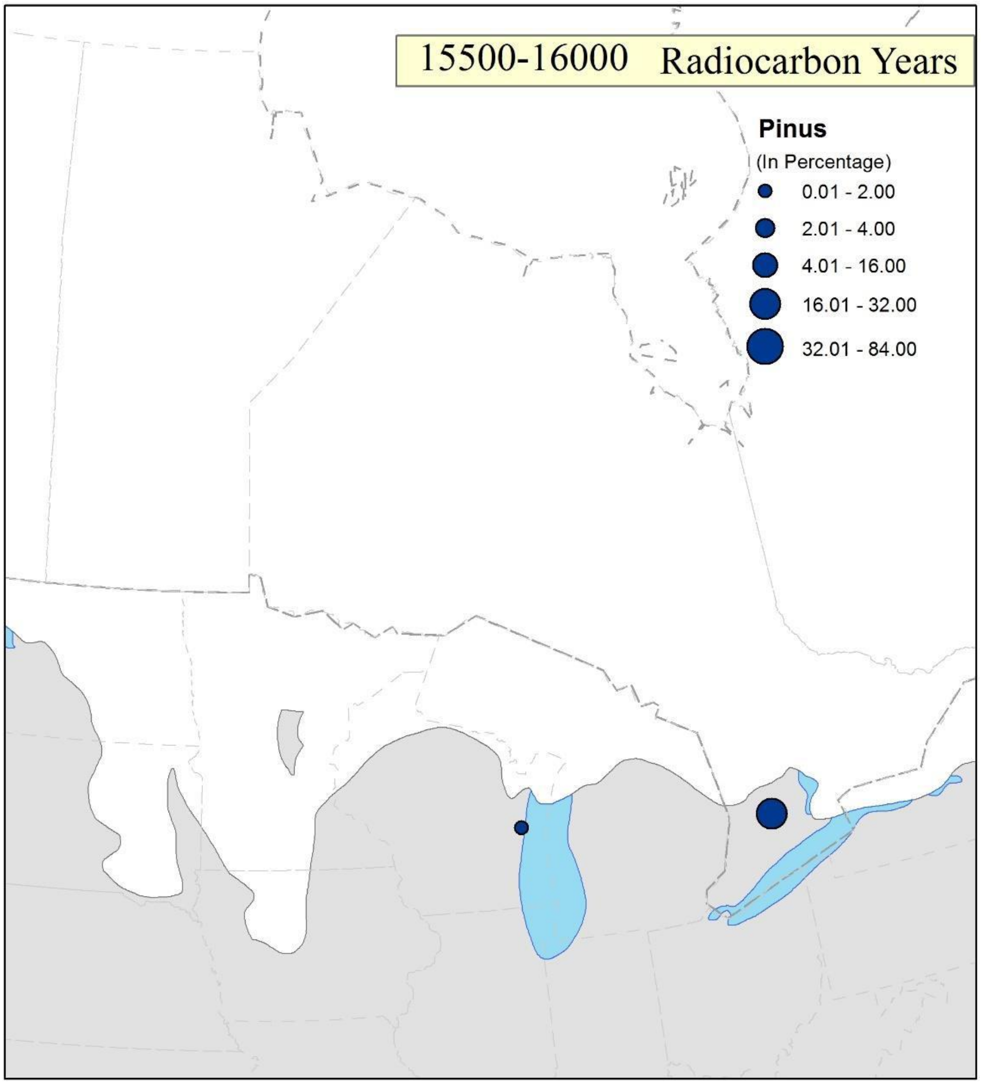

13500-13000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14000-13500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14500-14000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

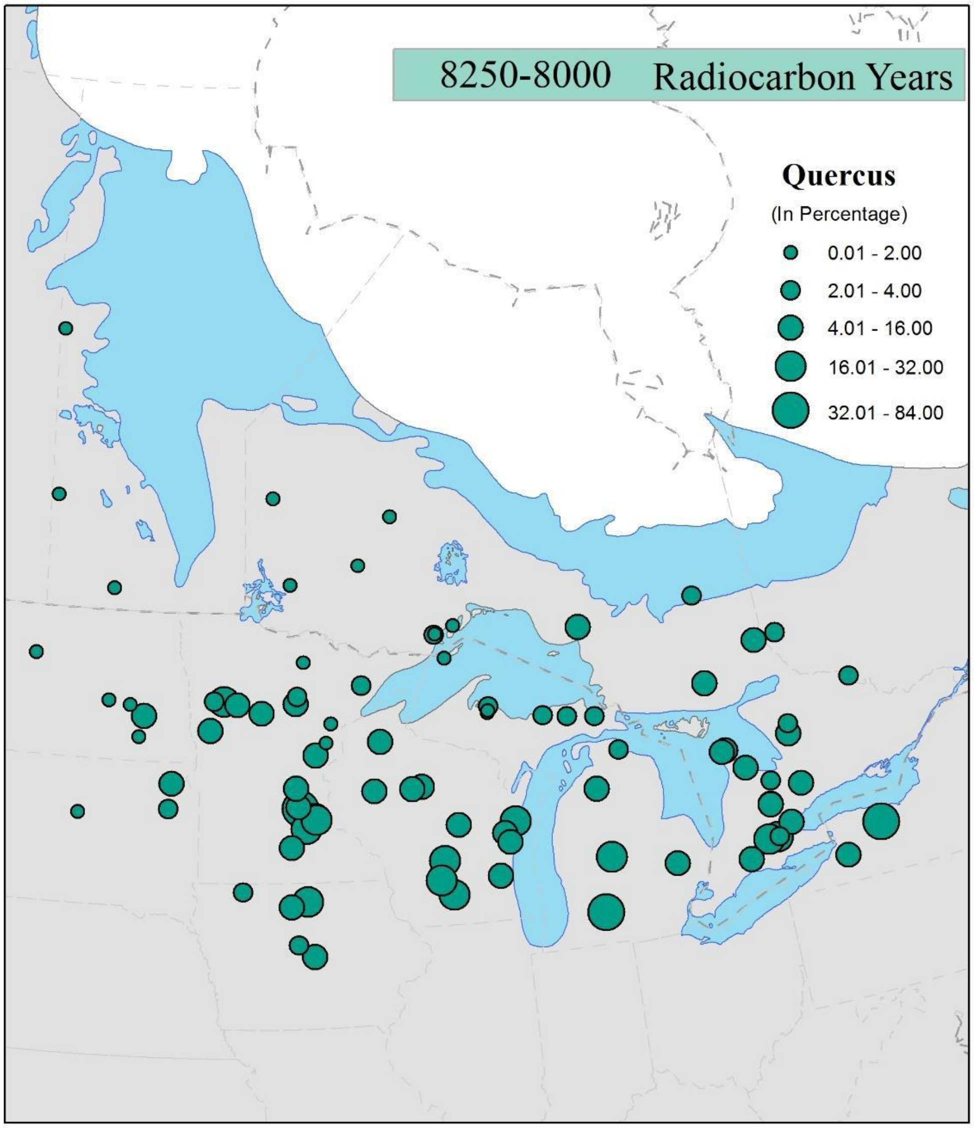

15000-14500 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

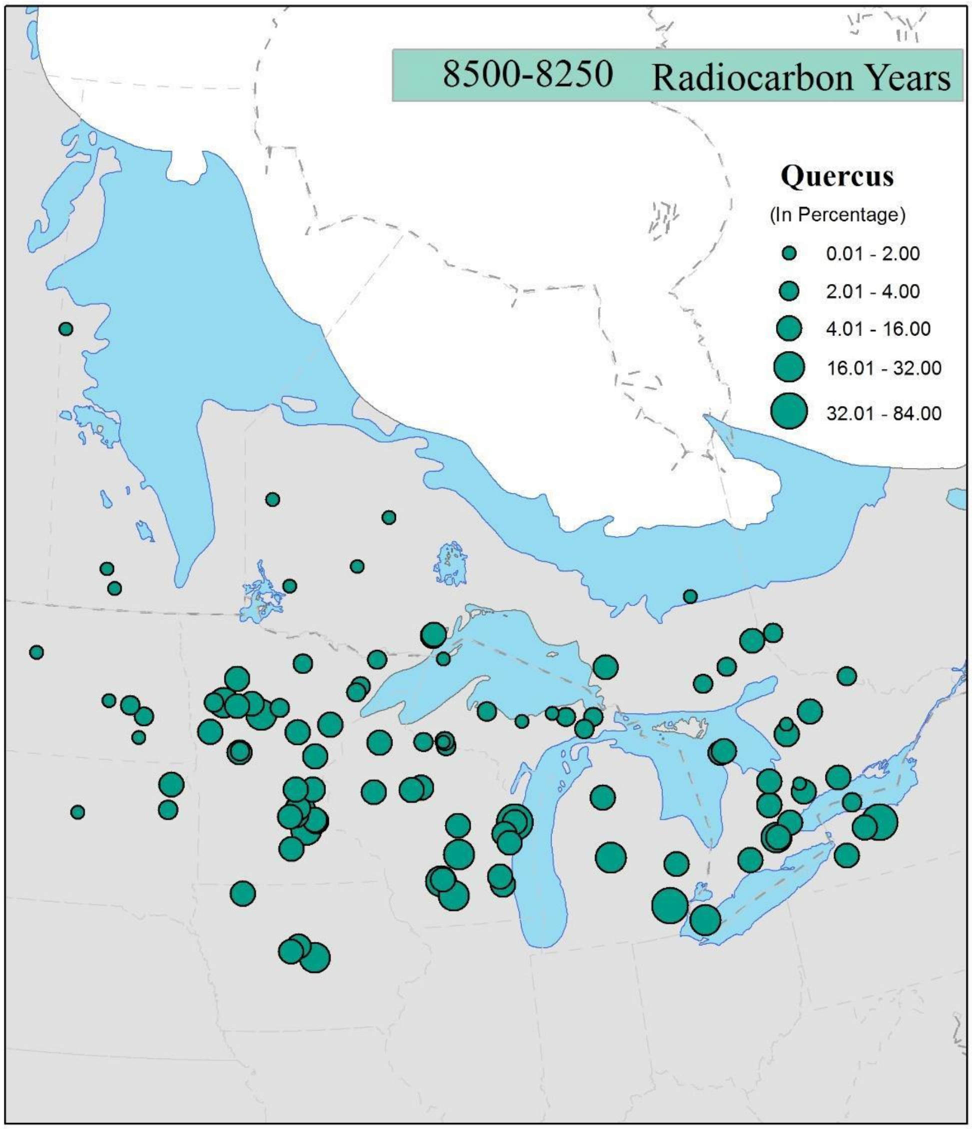

15500-15000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

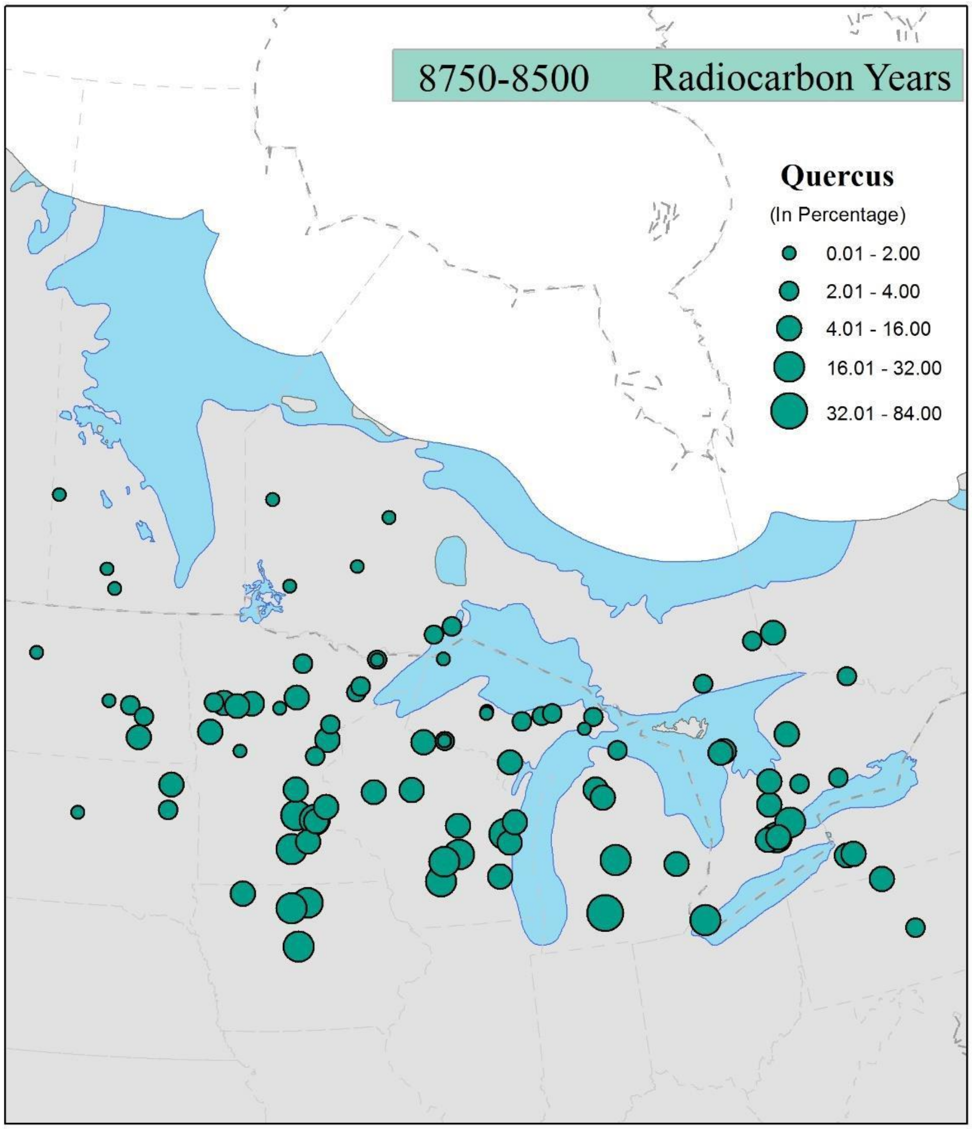

15500-16000 Radiocarbon Years
Pinus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

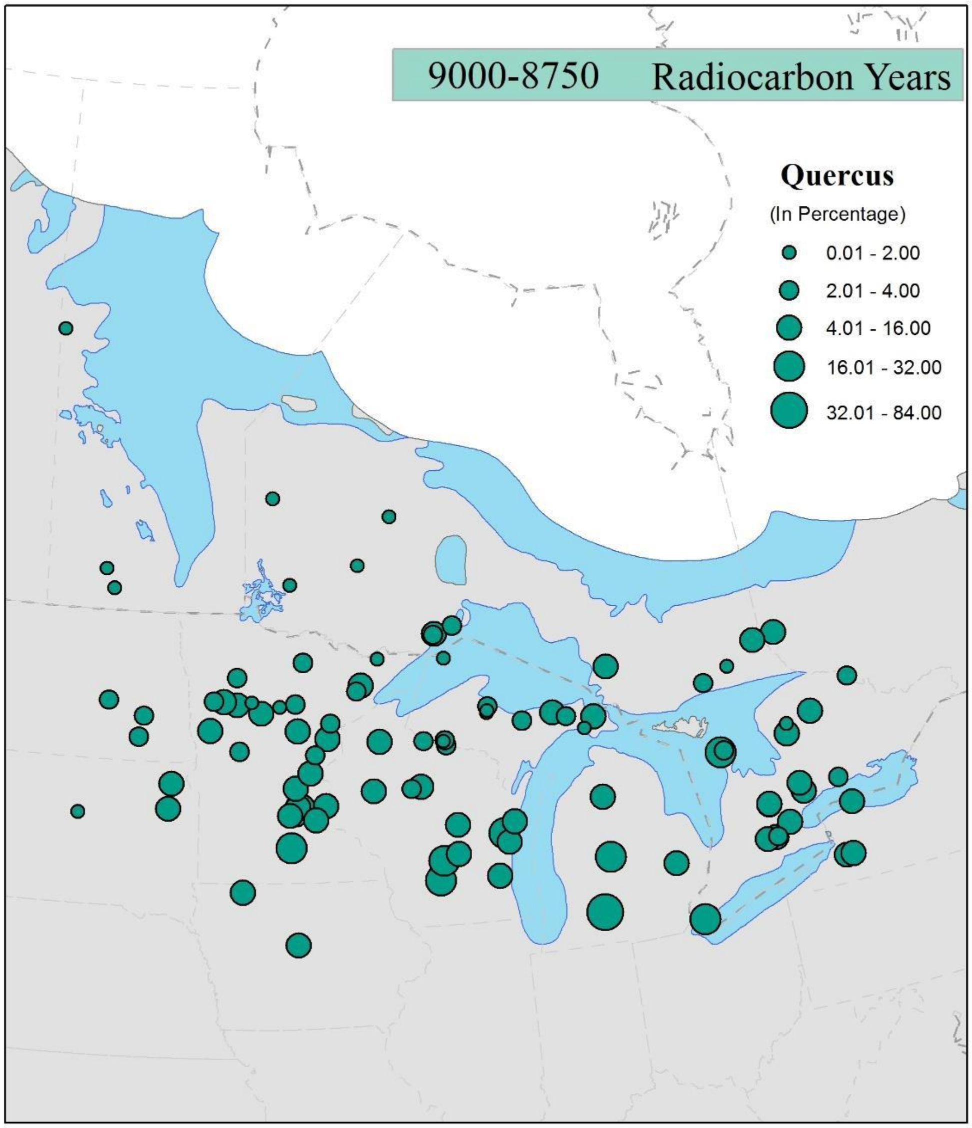
Appendix VII

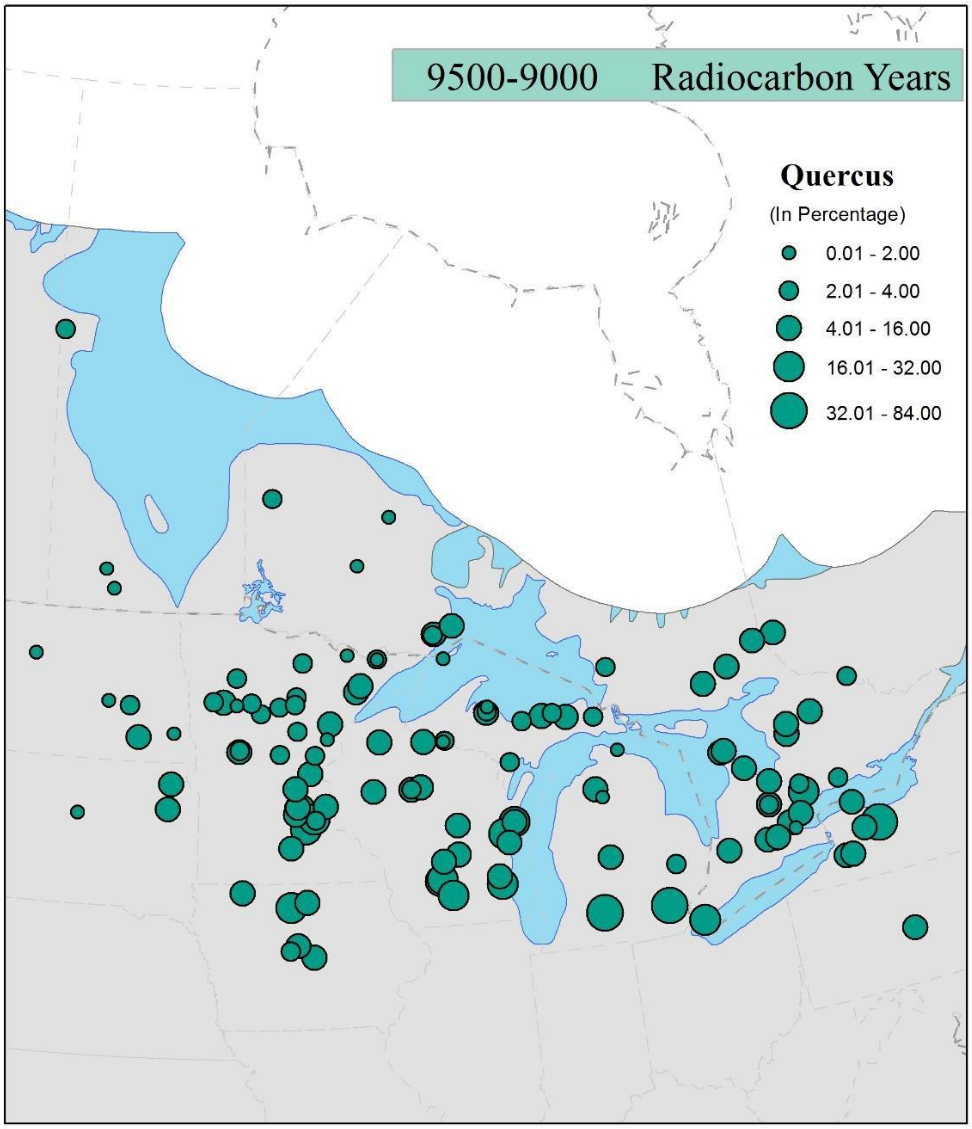
Pollen abundance of *Quercus*

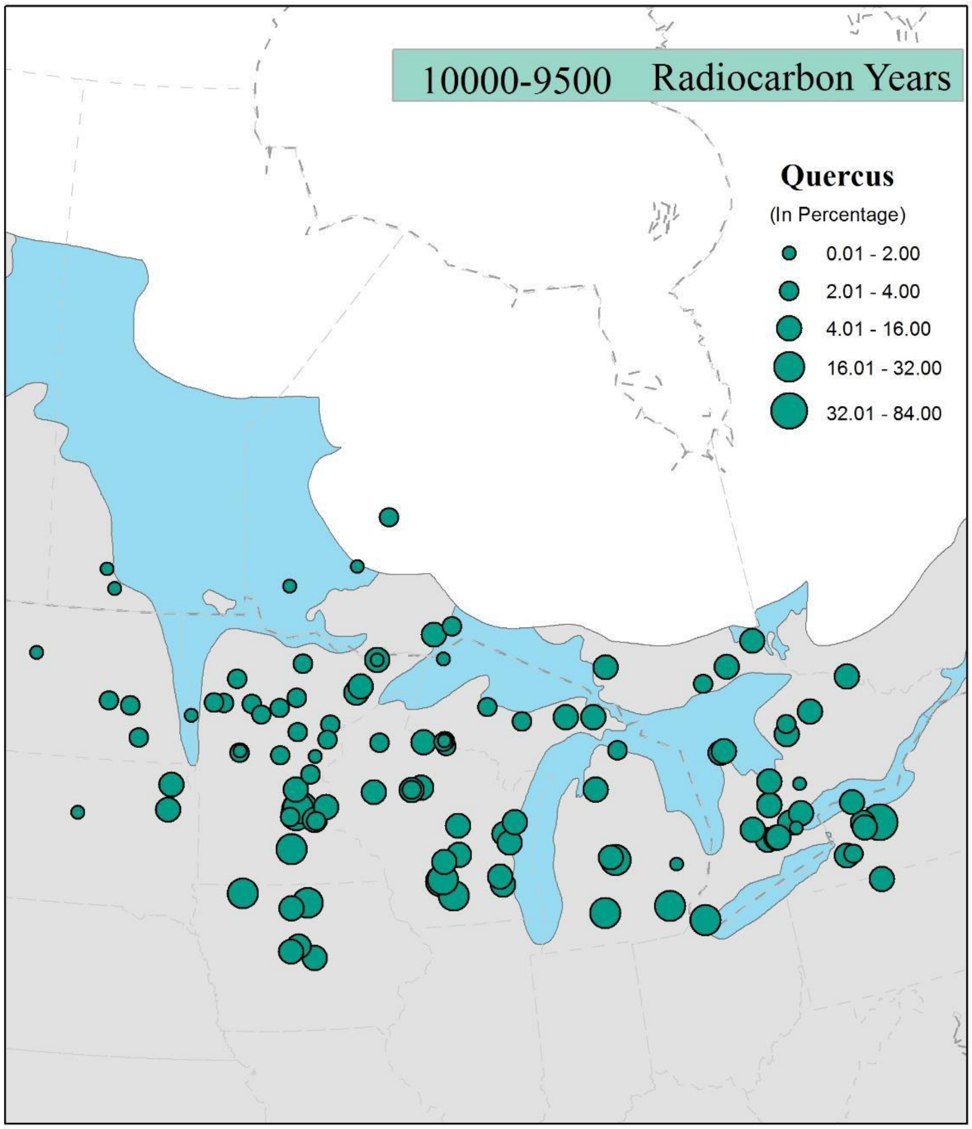

8250-8000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

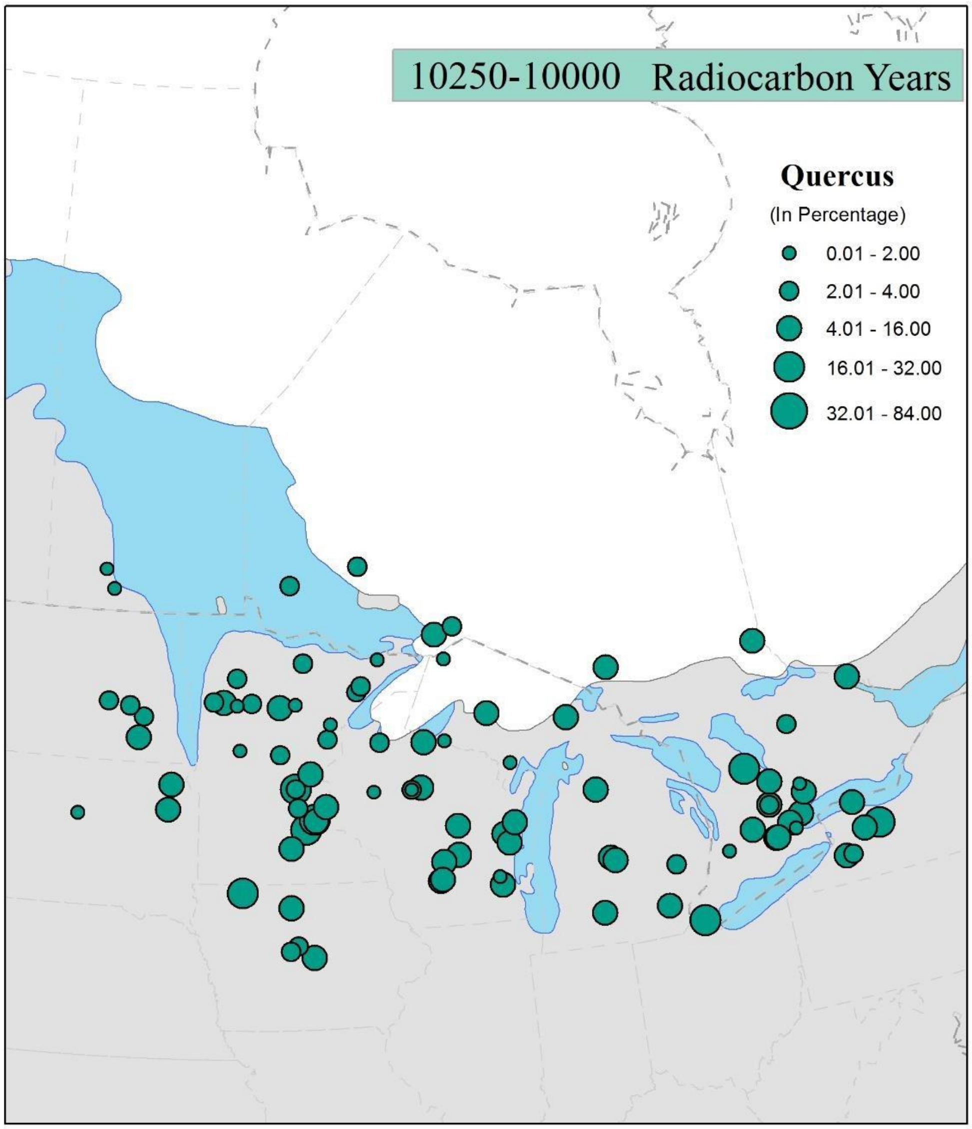

8500-8250 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

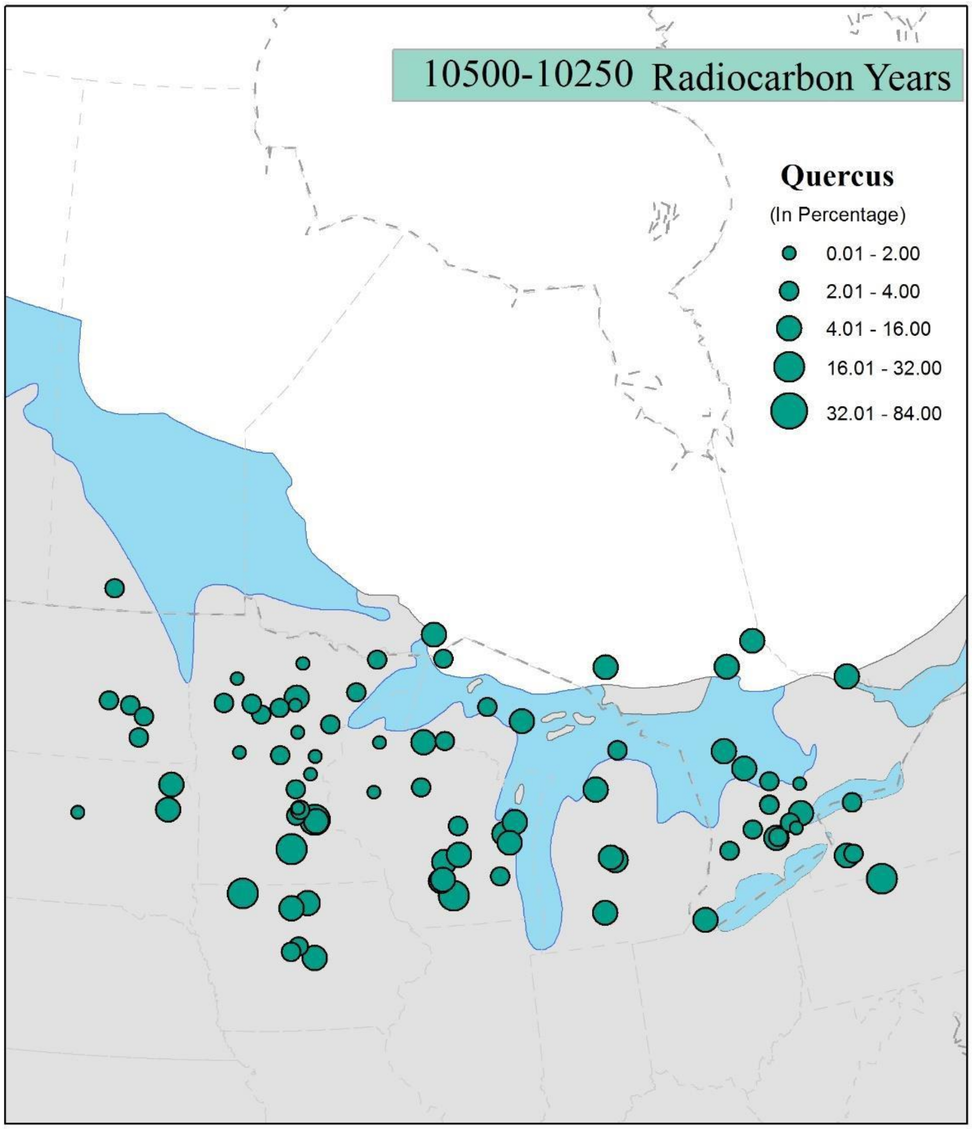

8750-8500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

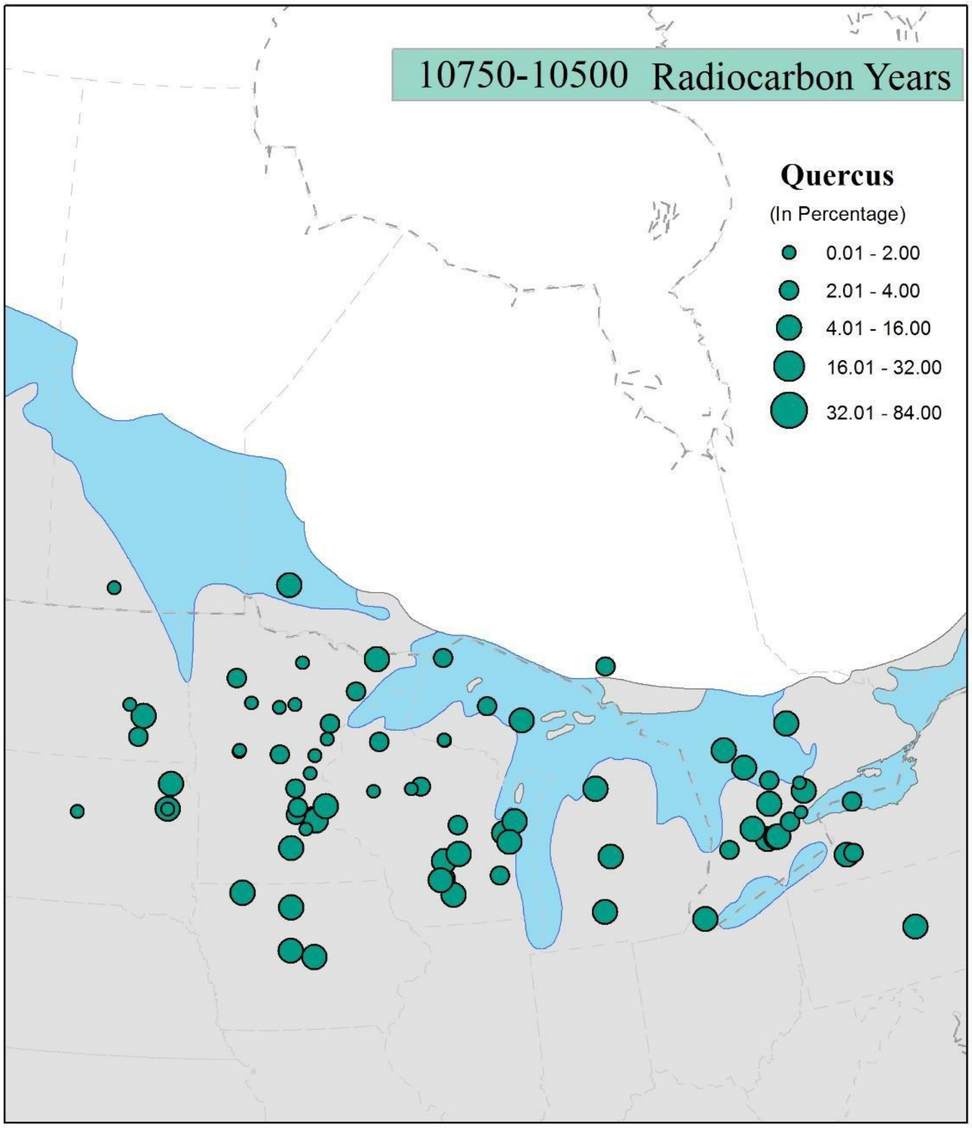

9000-8750 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

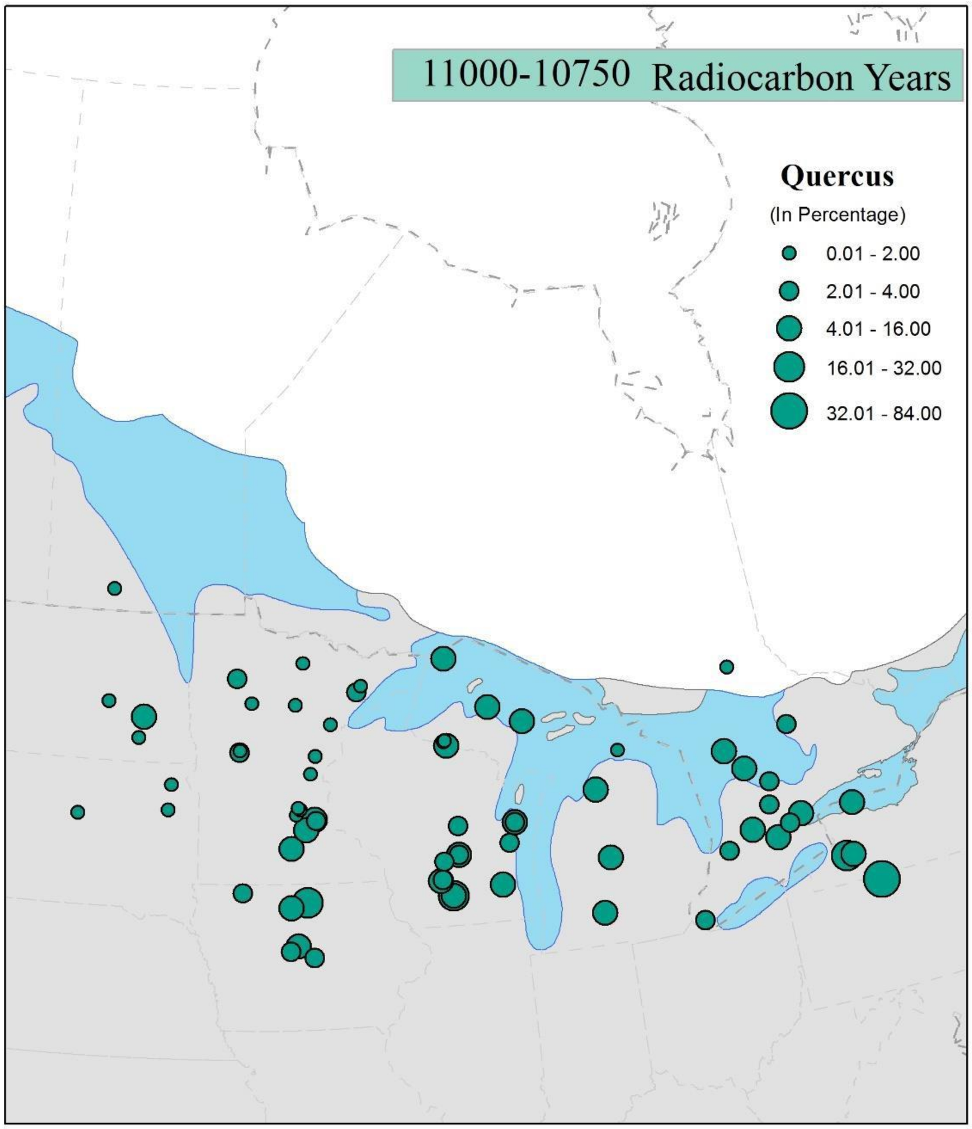

9500-9000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

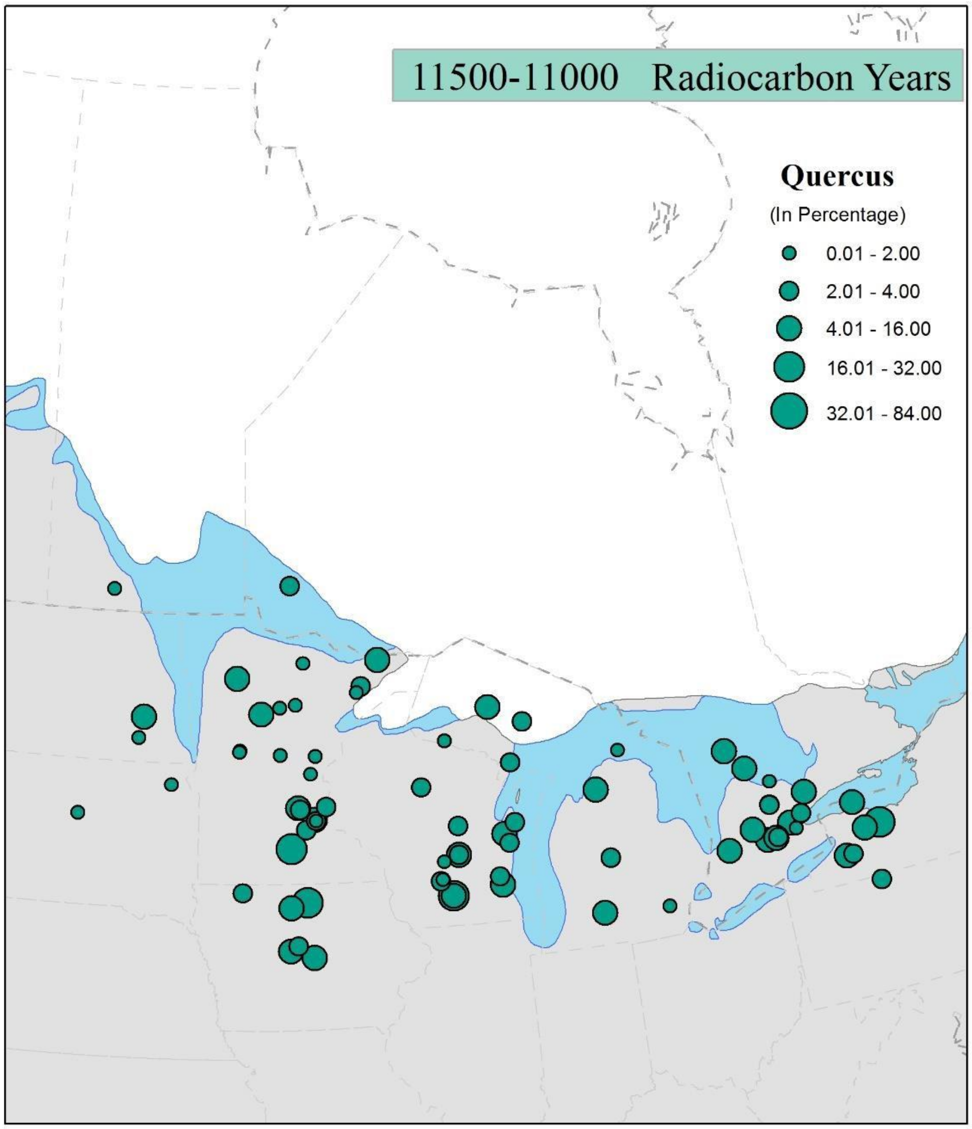

10000-9500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

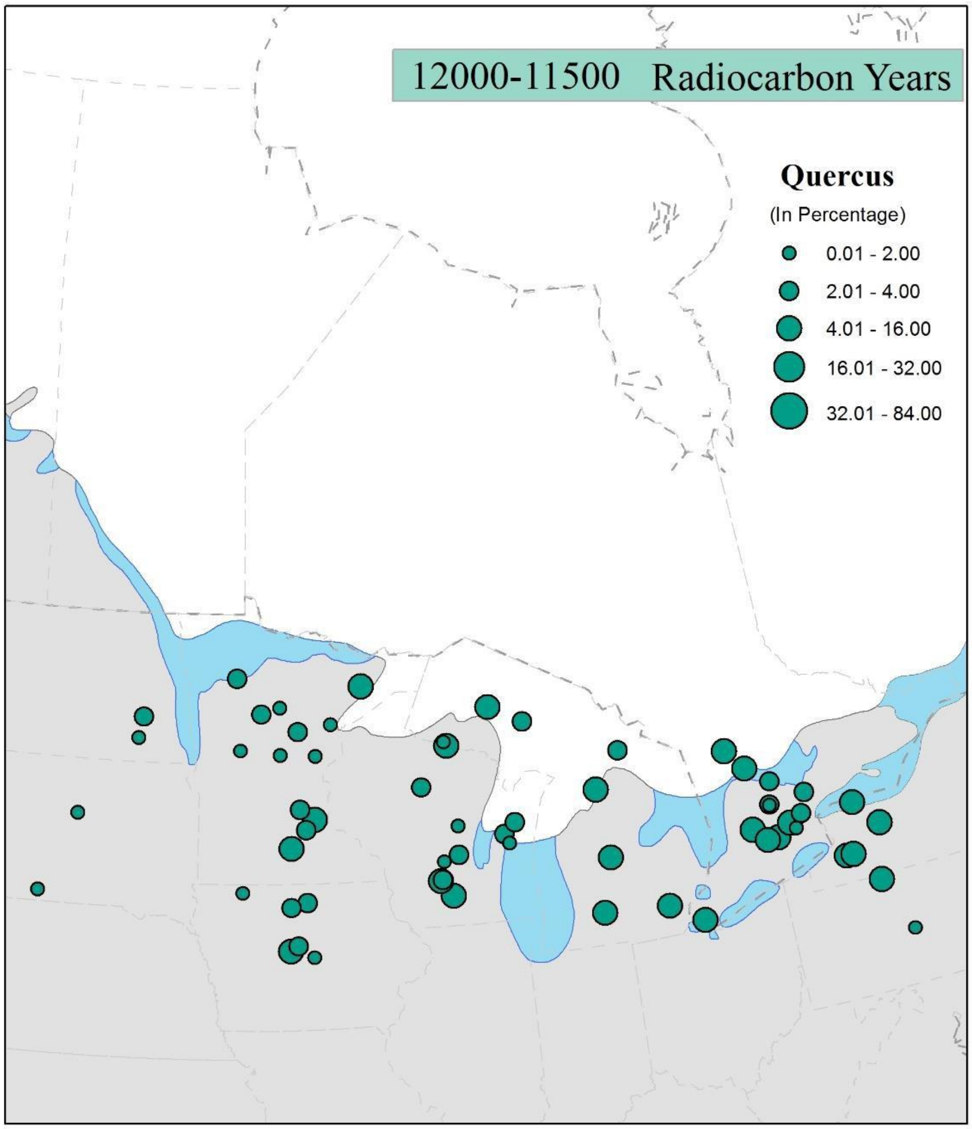

10250-10000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

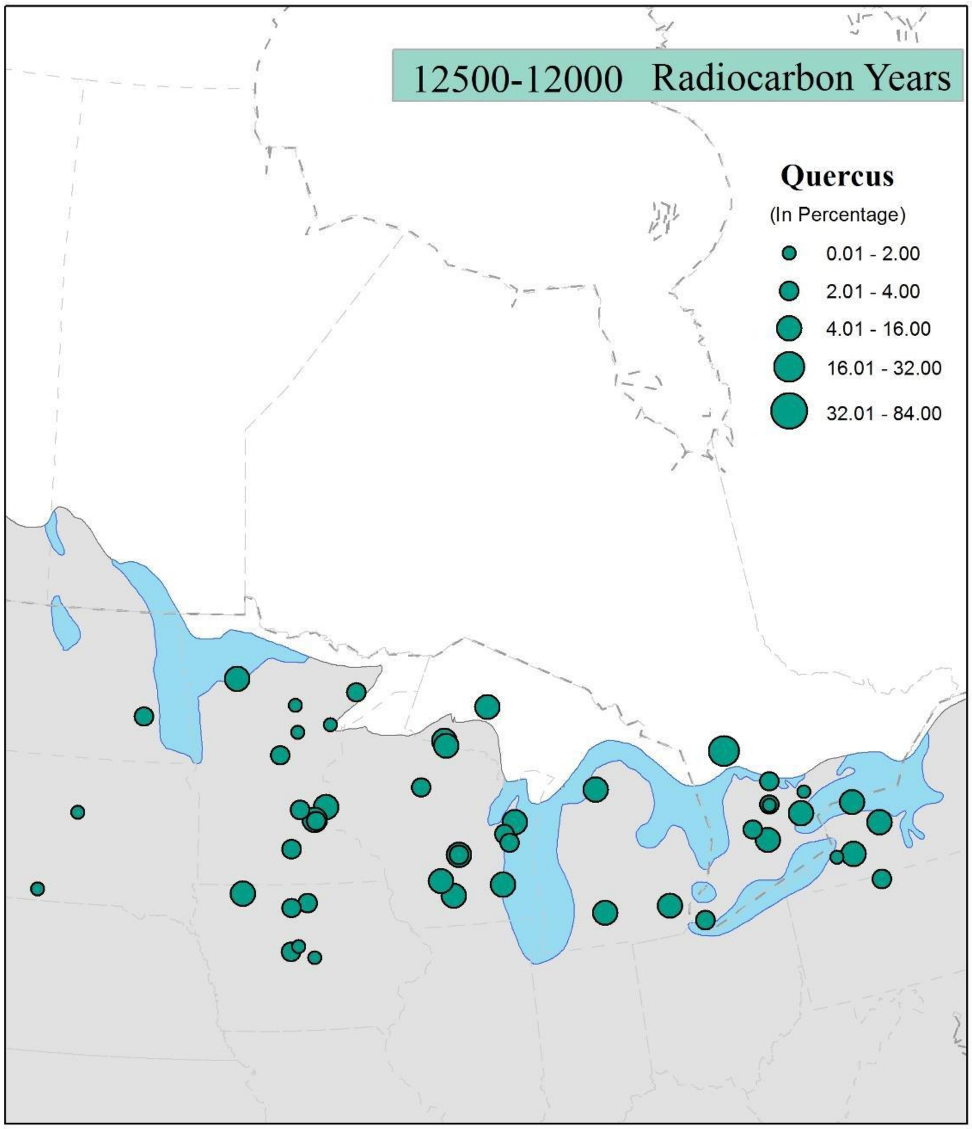

10500-10250 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

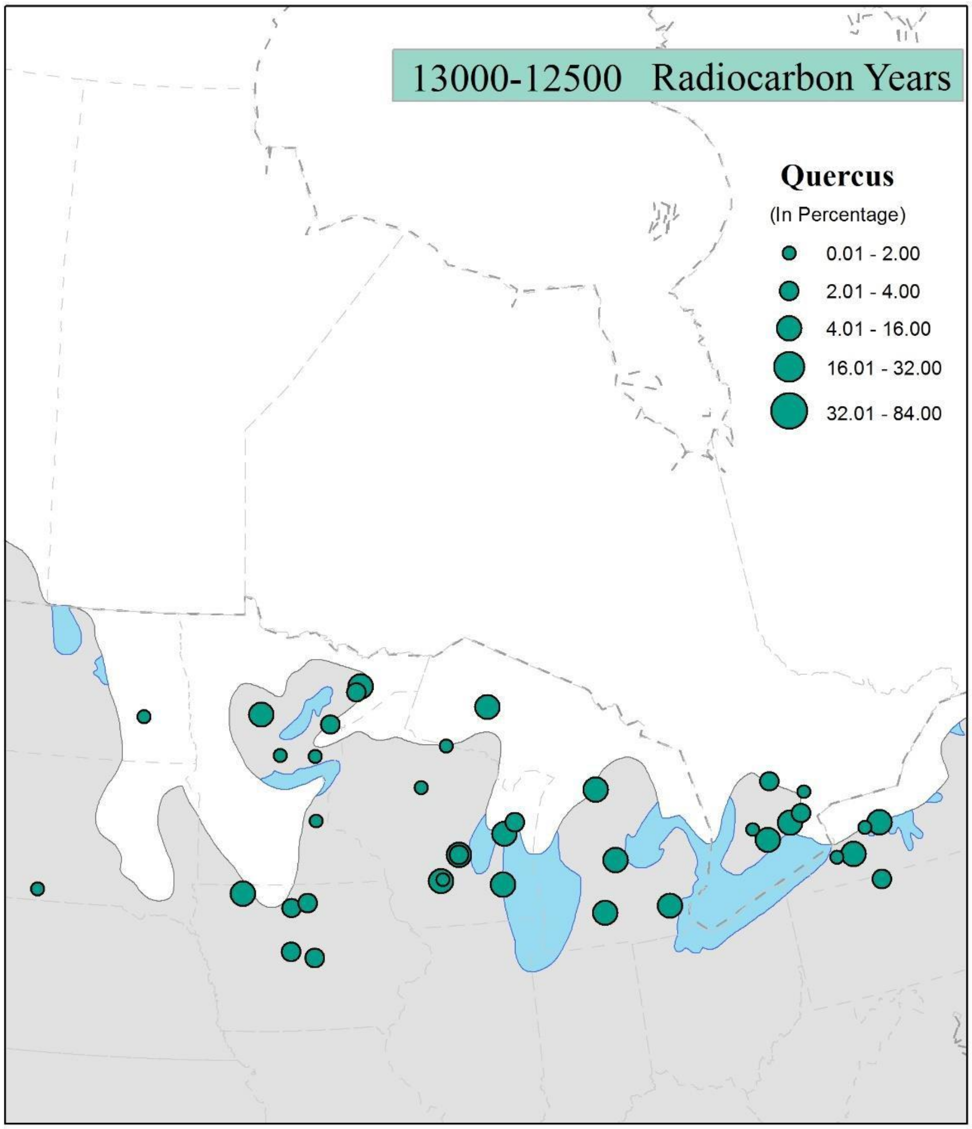

10750-10500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

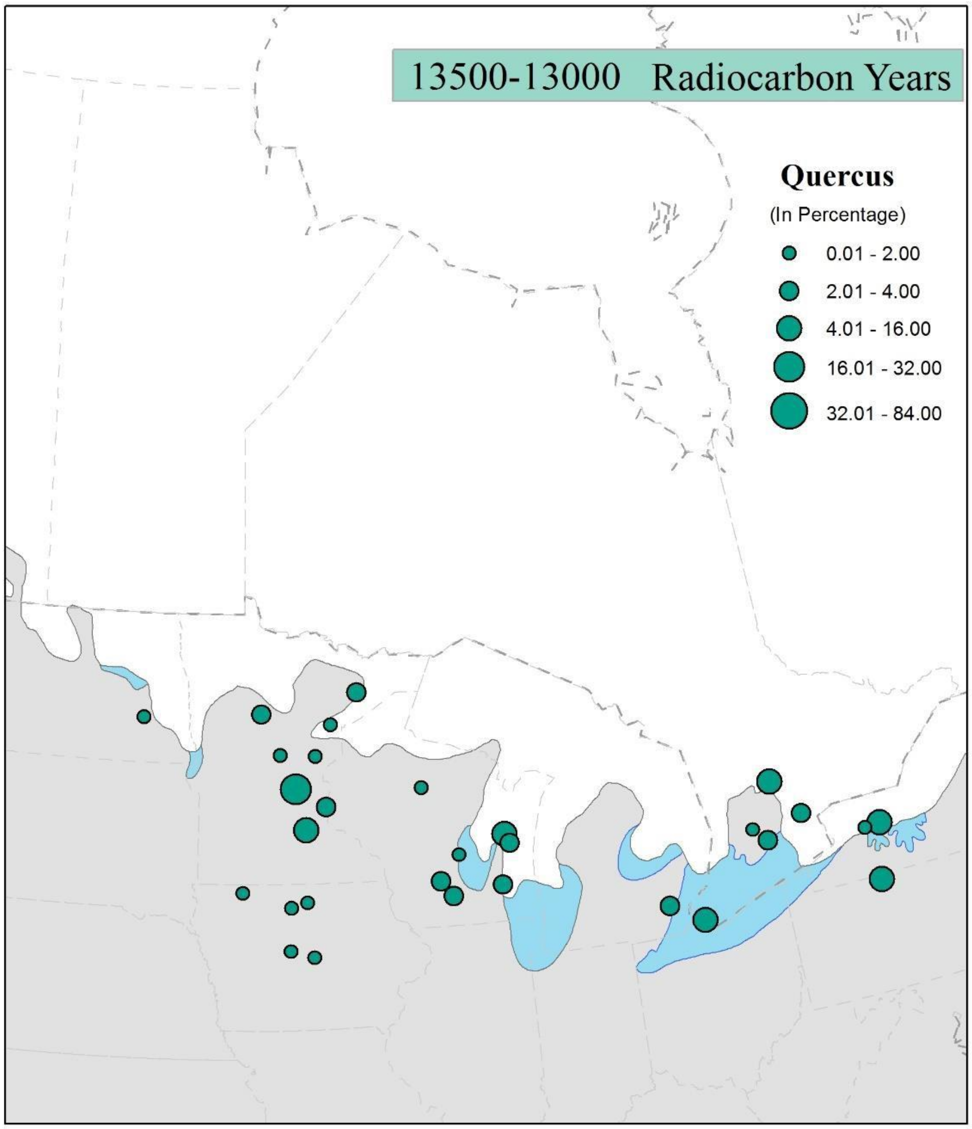

11000-10750 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

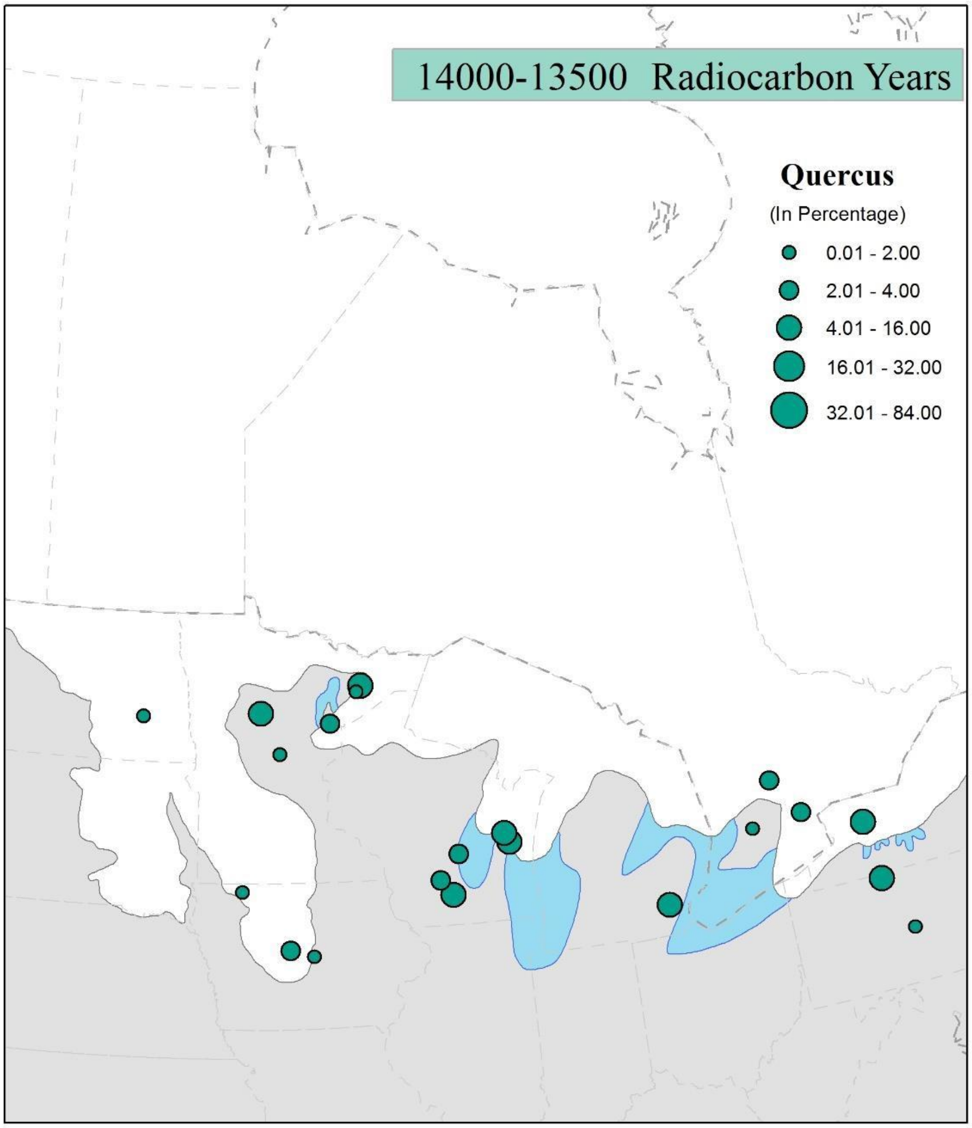

11500-11000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

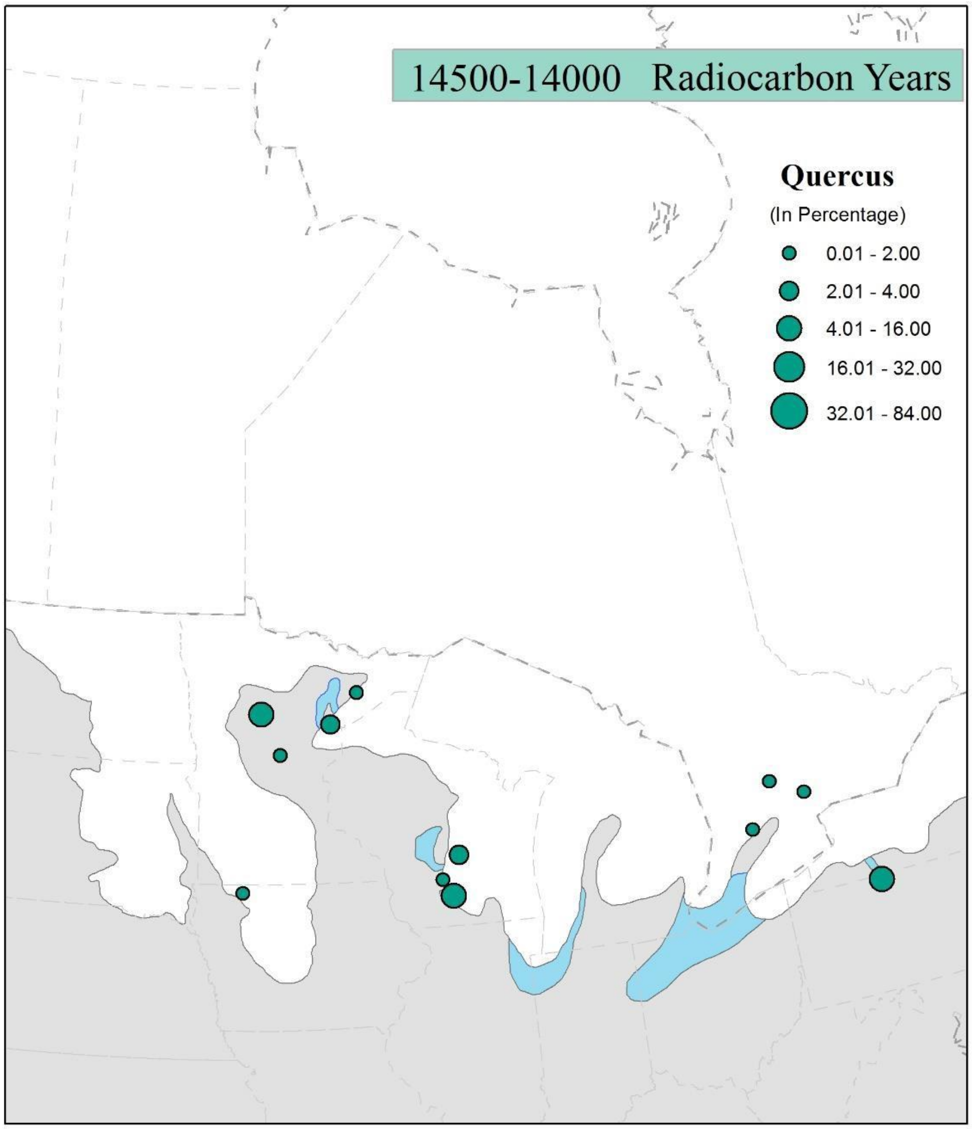

12000-11500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

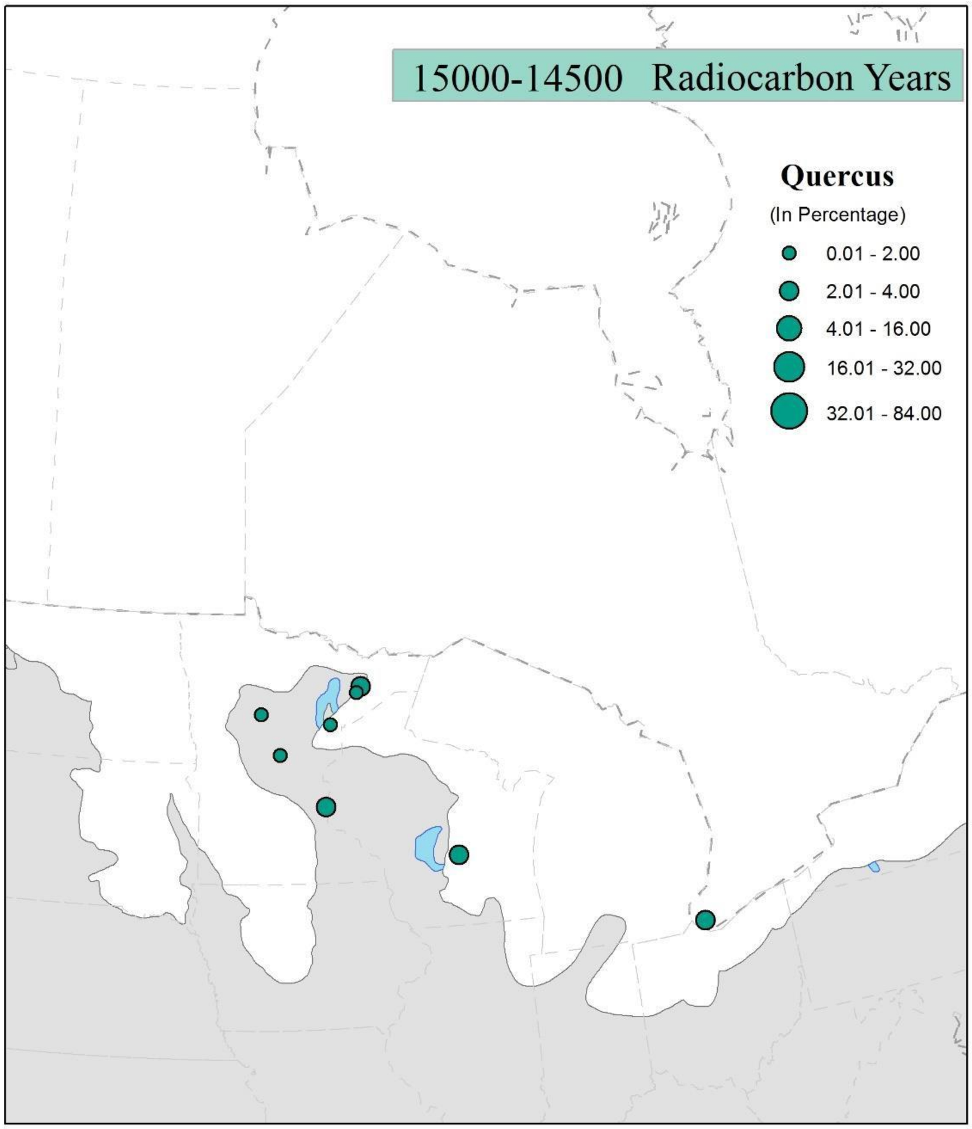

12500-12000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

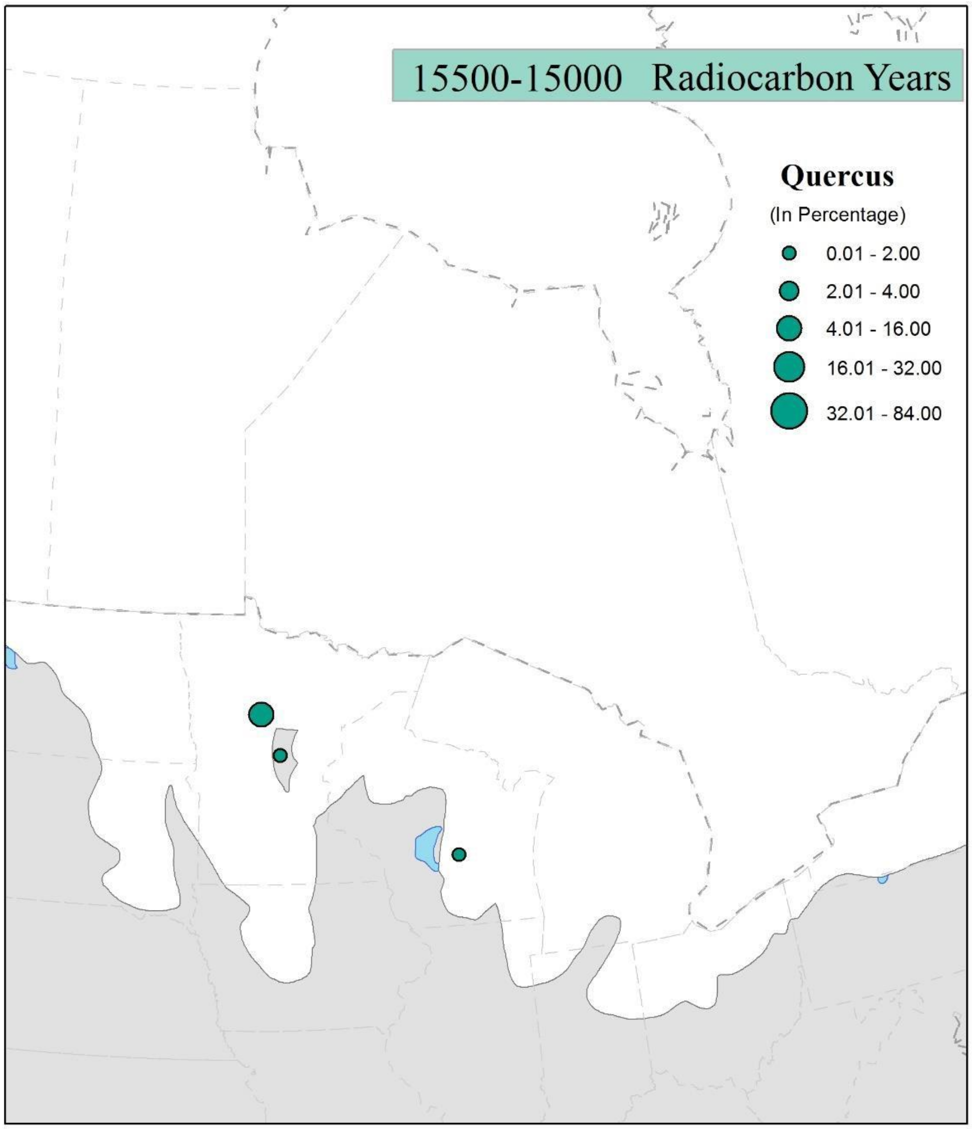

13000-12500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

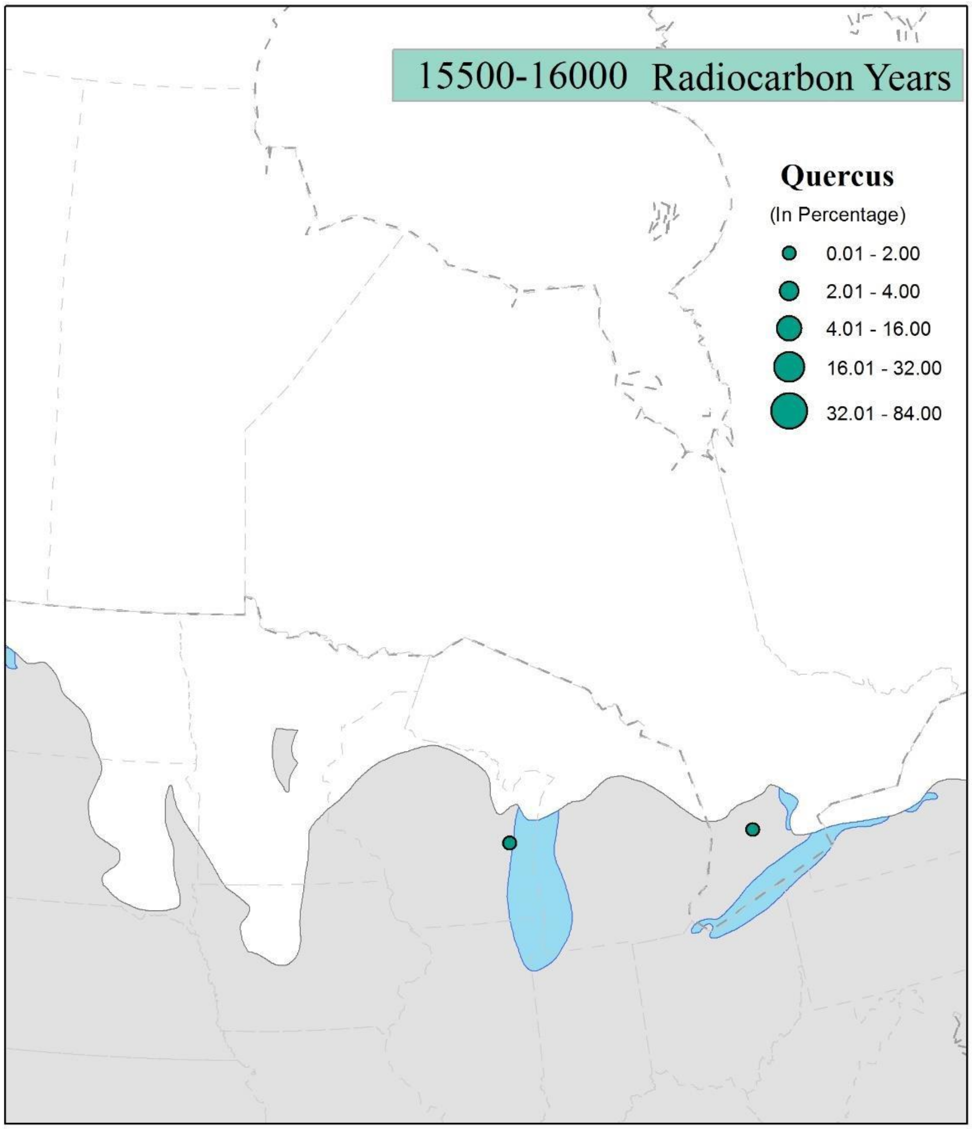

13500-13000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14000-13500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14500-14000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

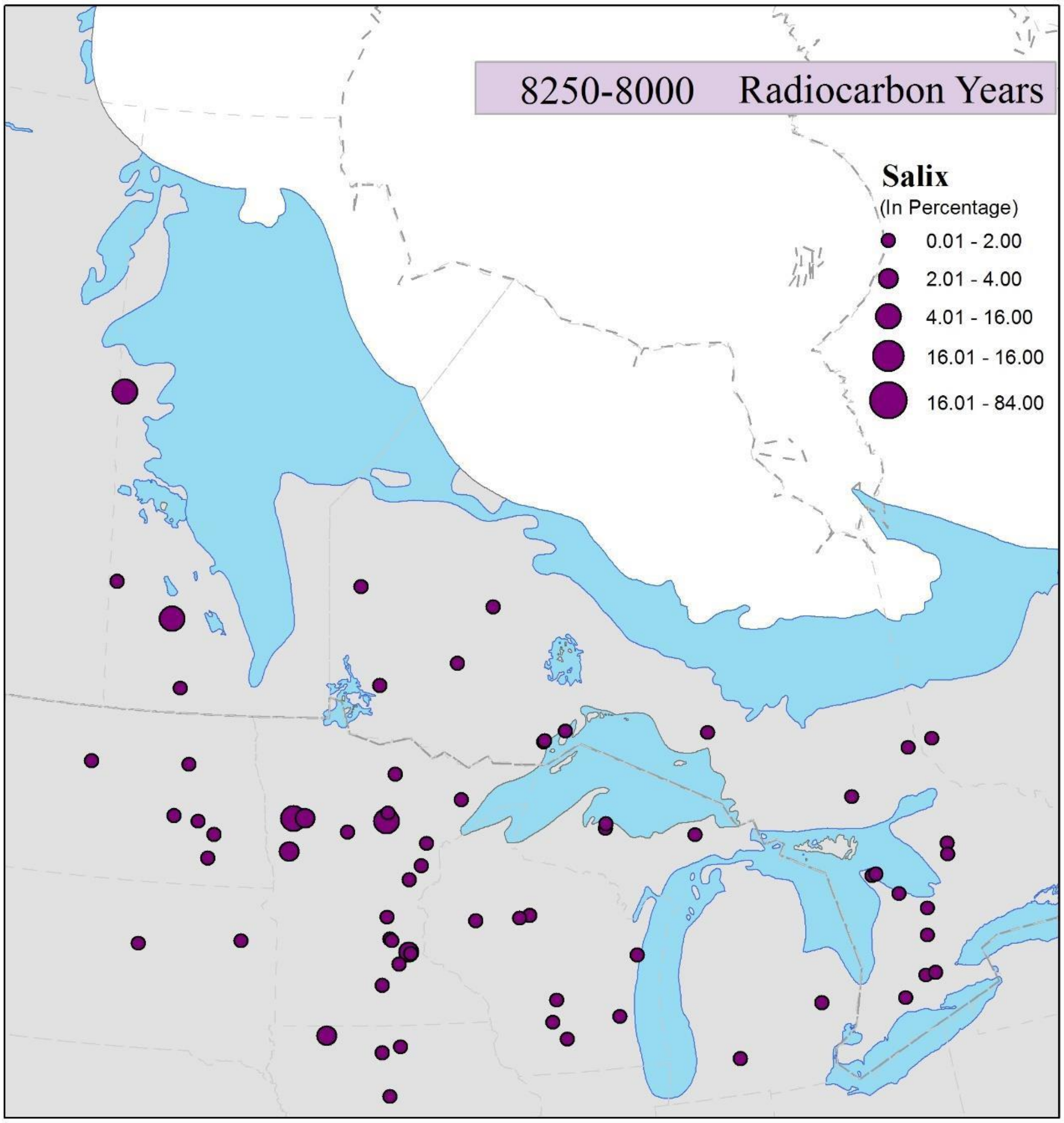

15000-14500 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


15500-15000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

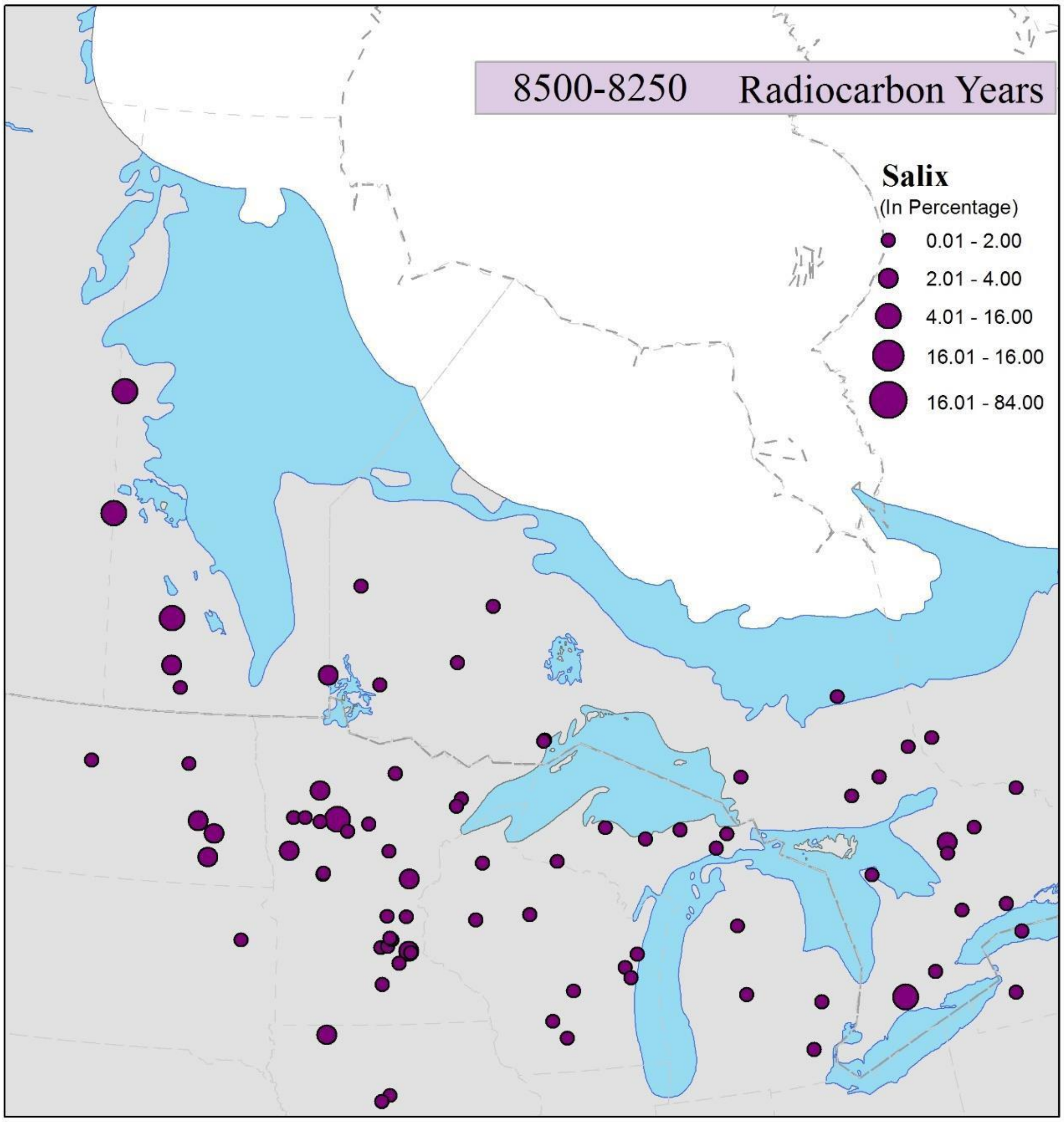

15500-16000 Radiocarbon Years
Quercus
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

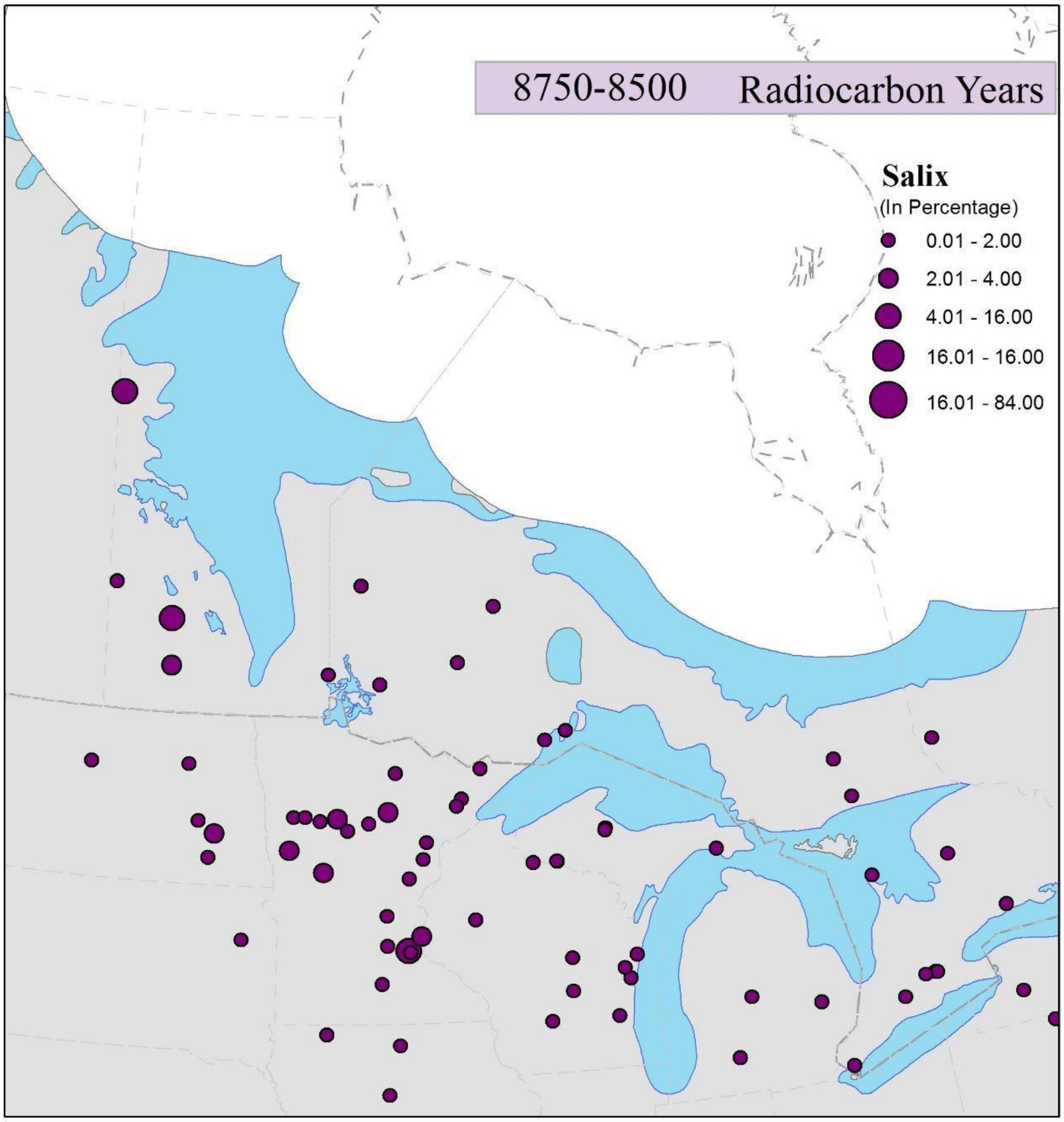
Appendix VIII

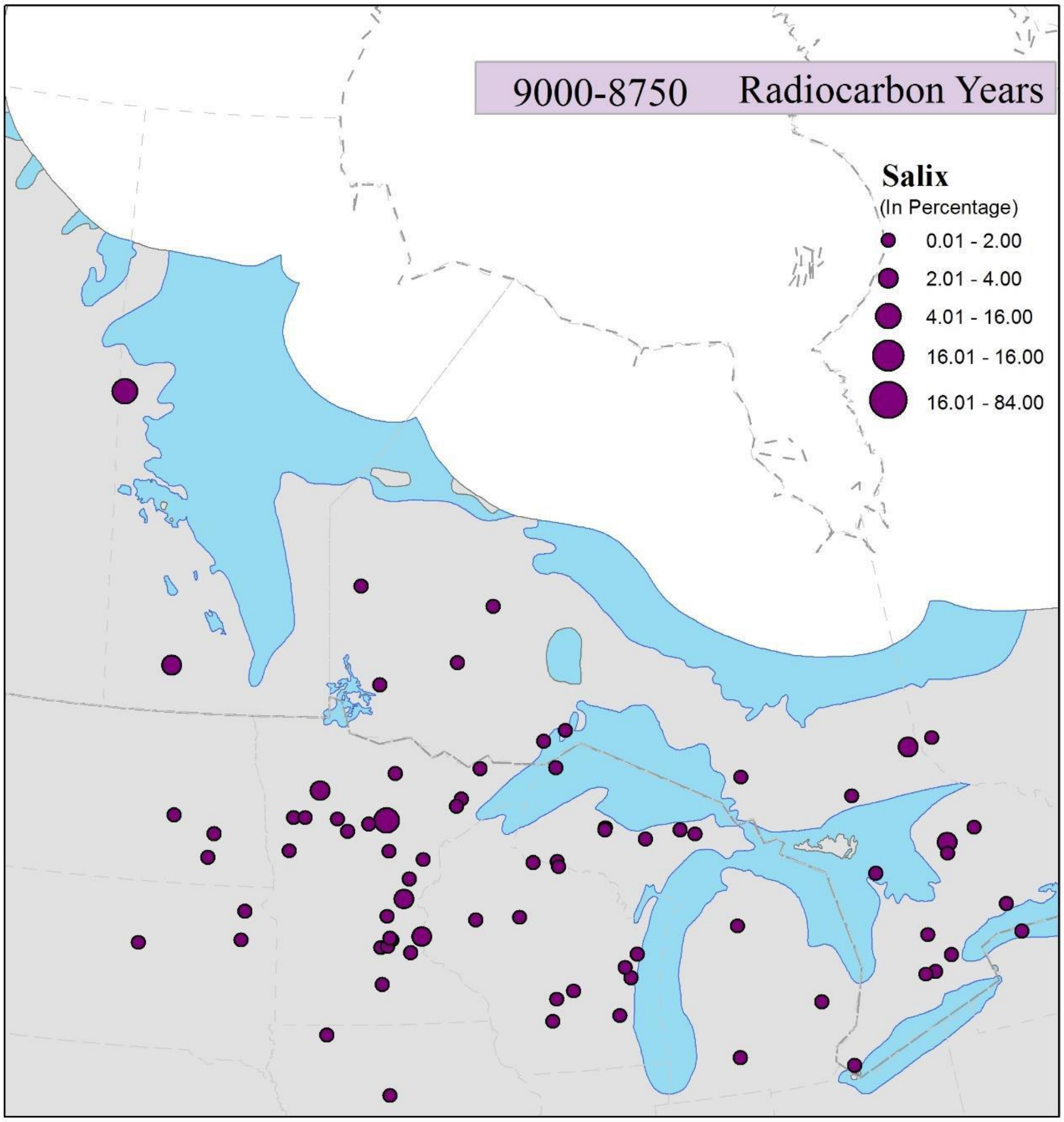
Pollen abundance of *Salix*

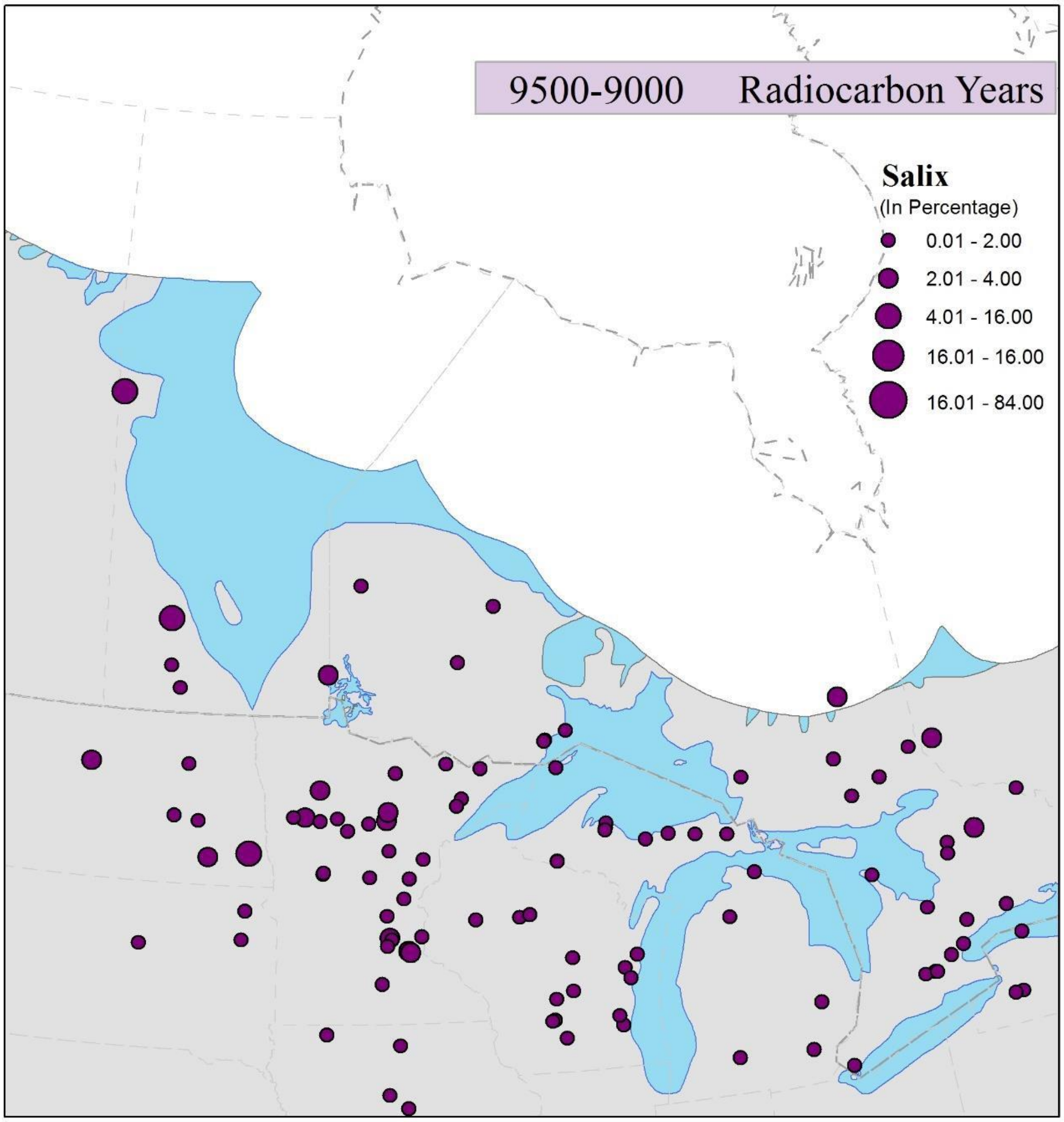


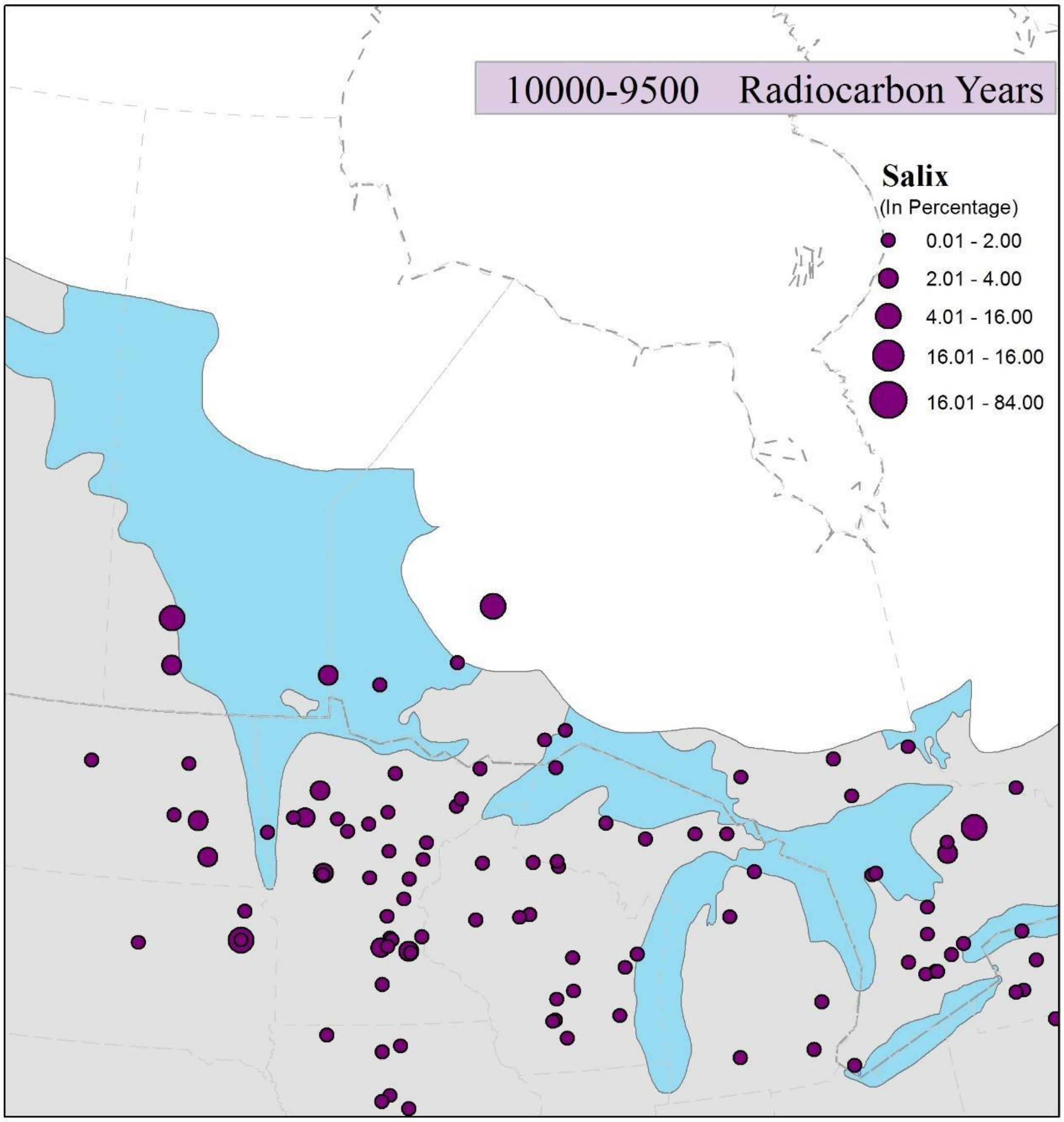
8250-8000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

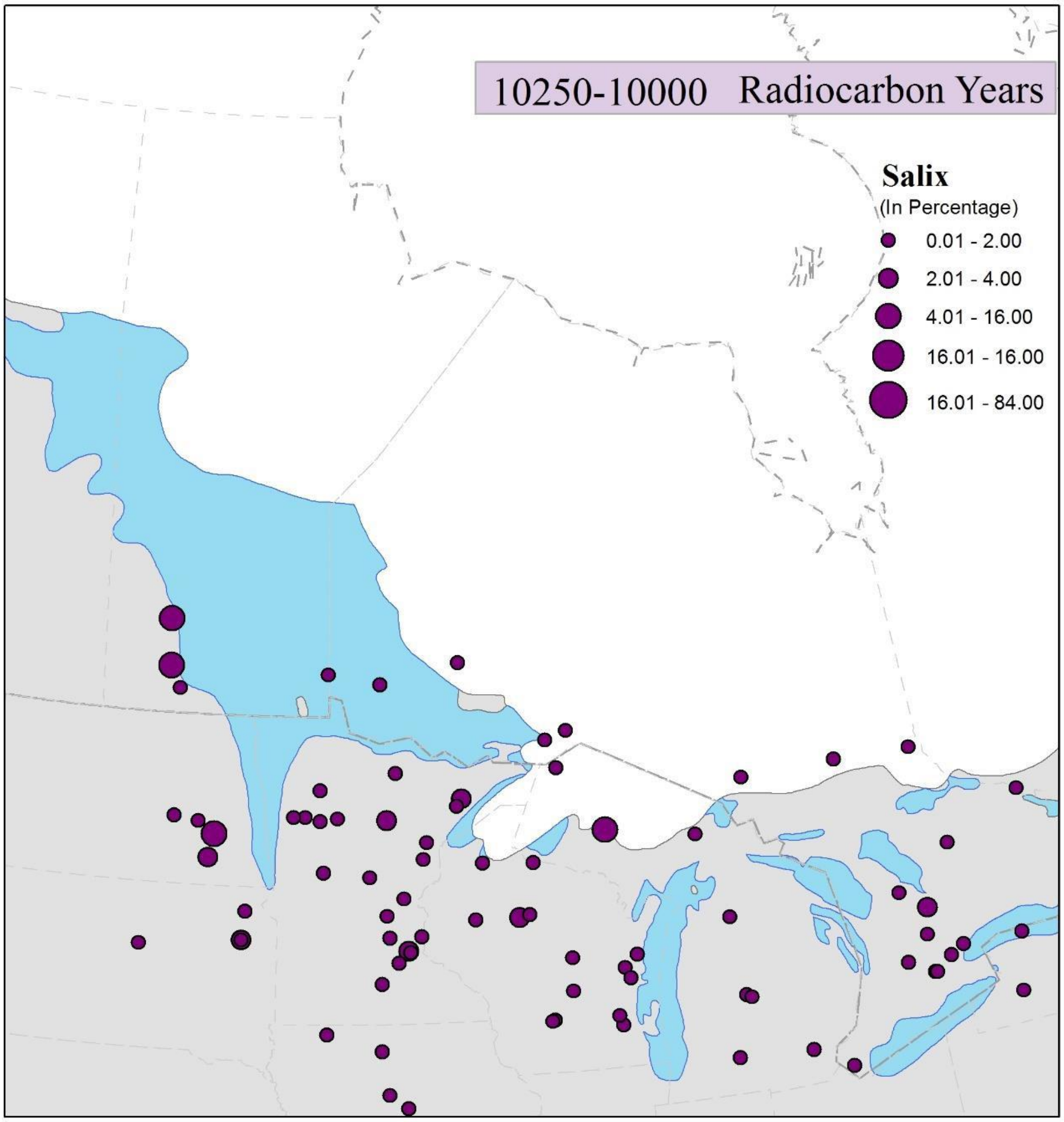

8500-8250 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

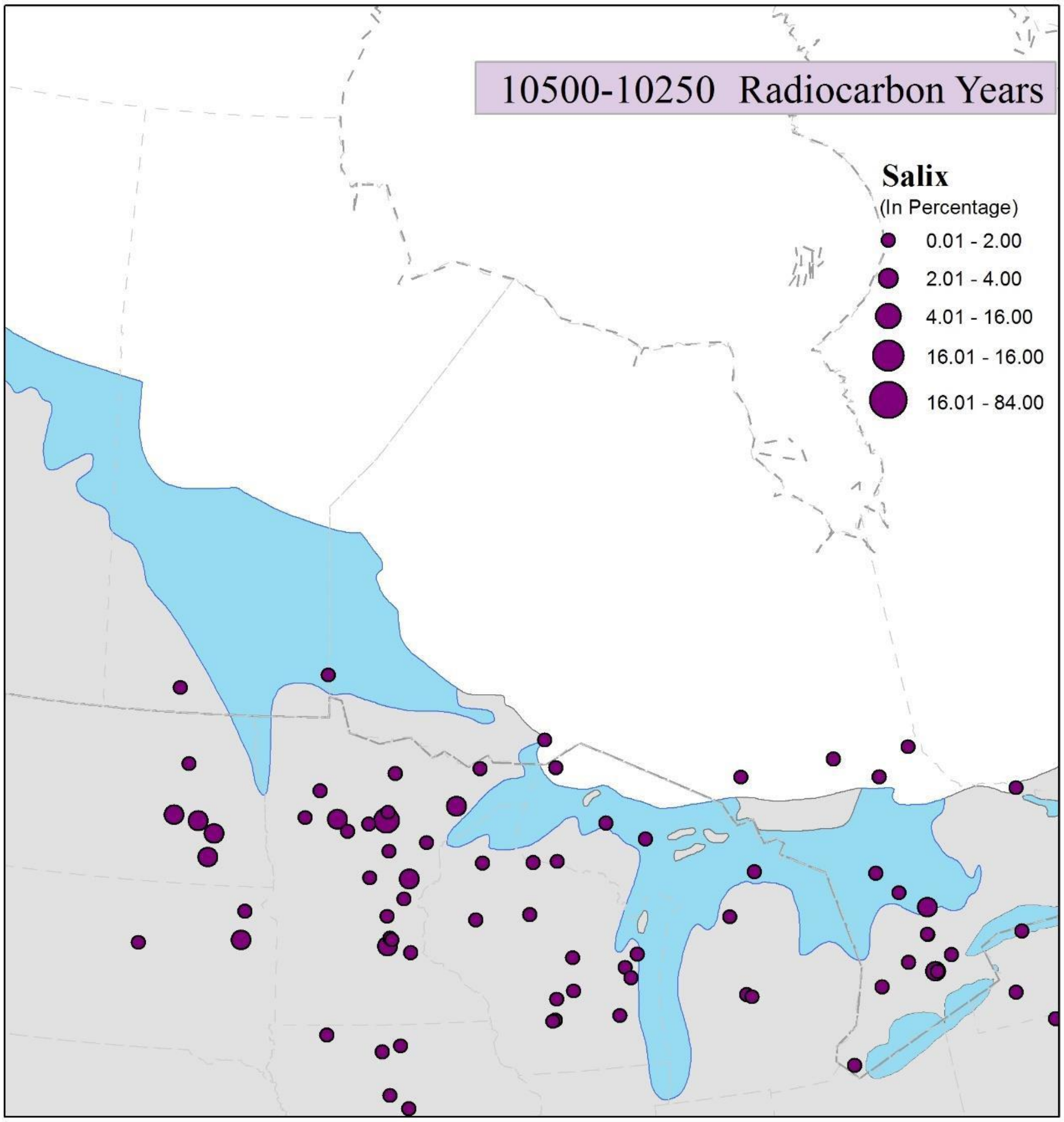

8750-8500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

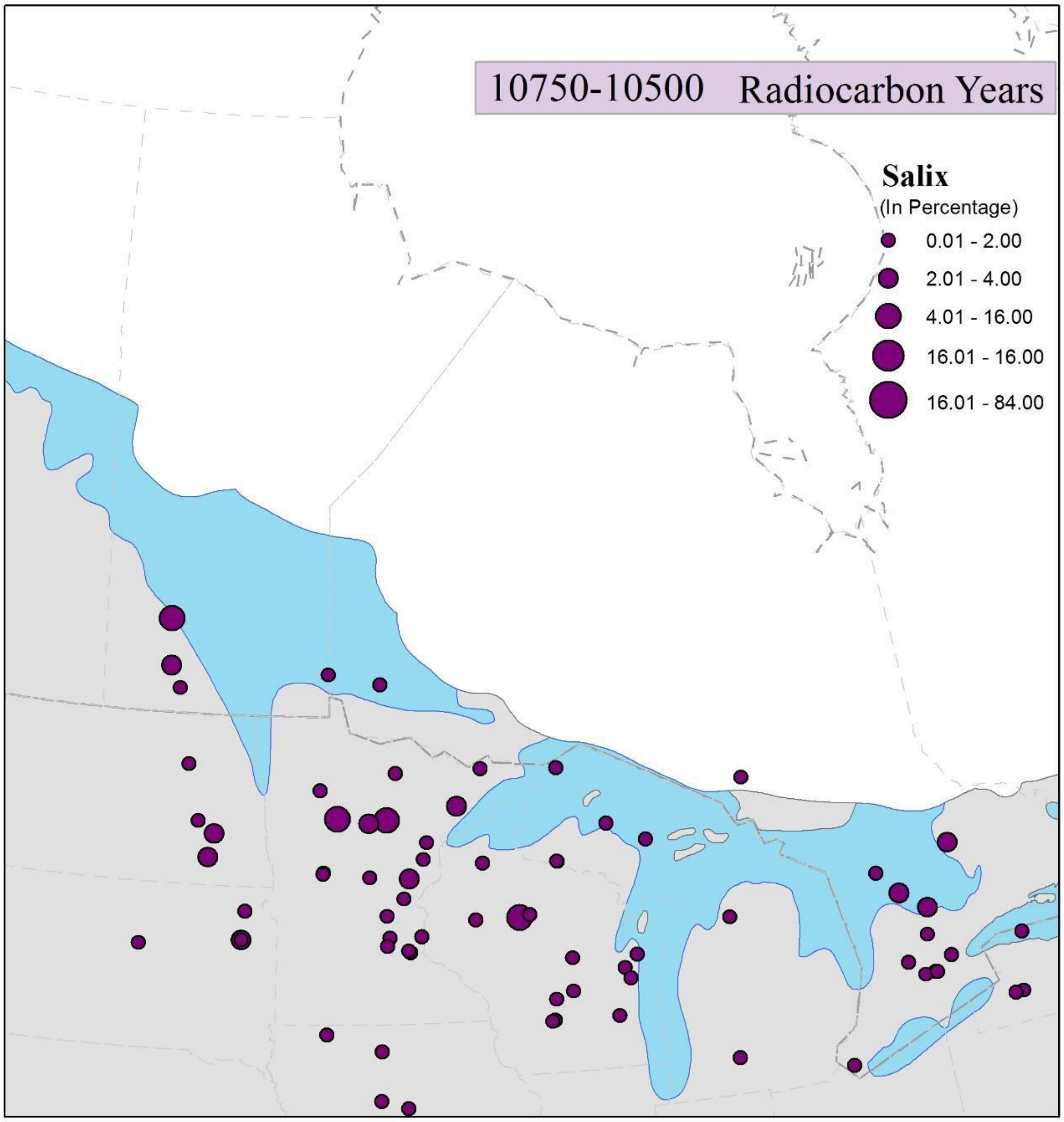

9000-8750 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

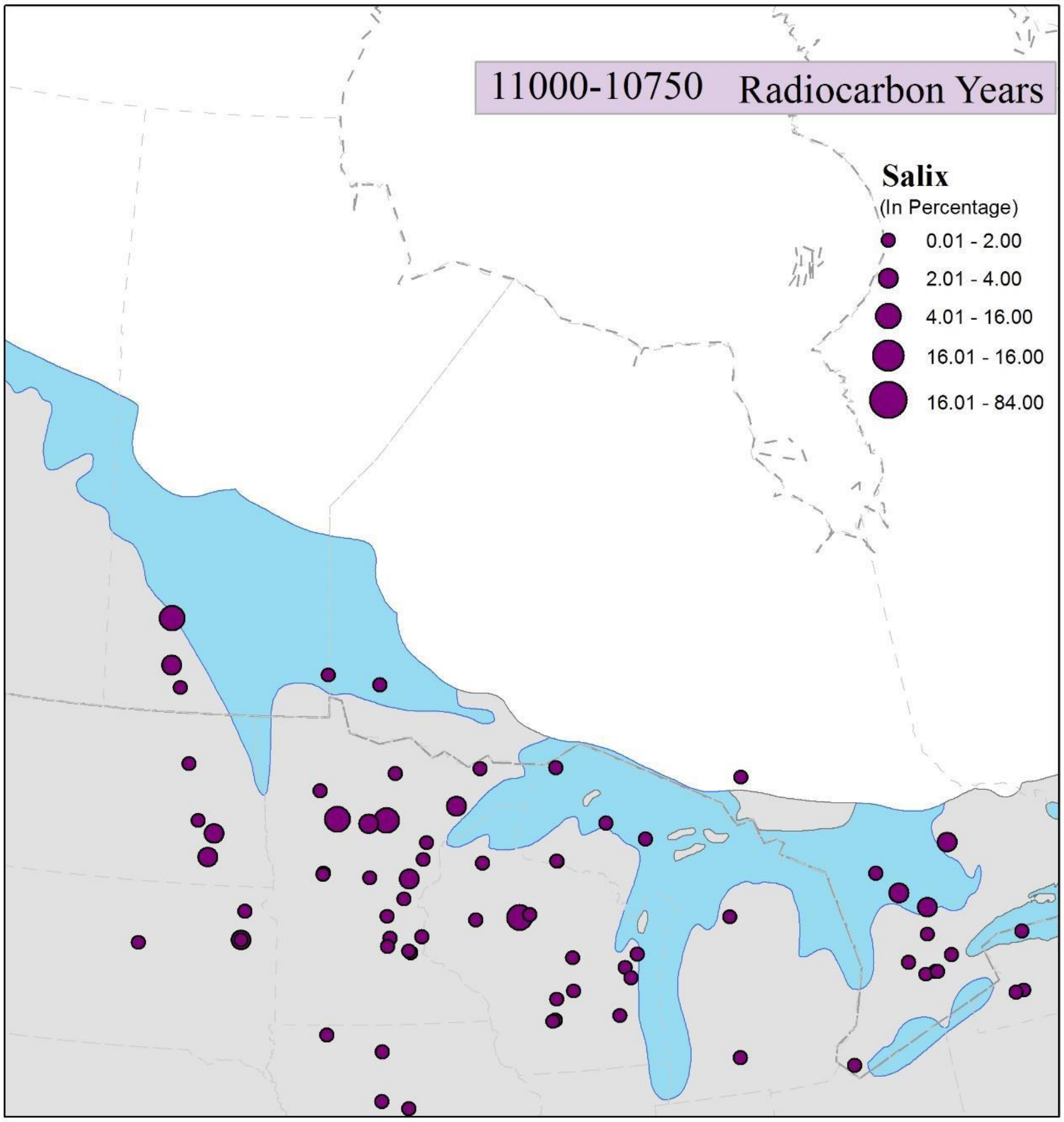

9500-9000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

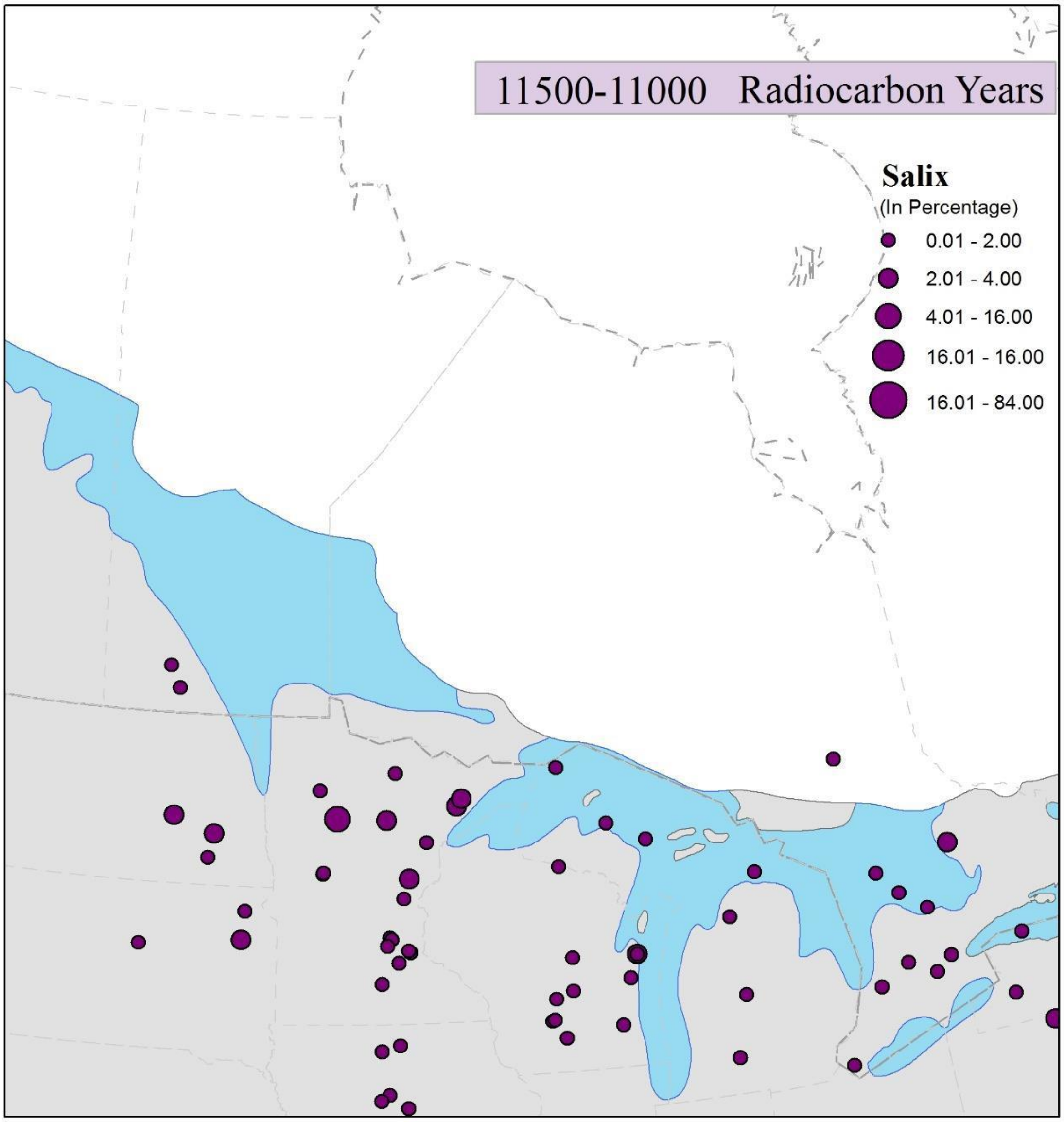

10000-9500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

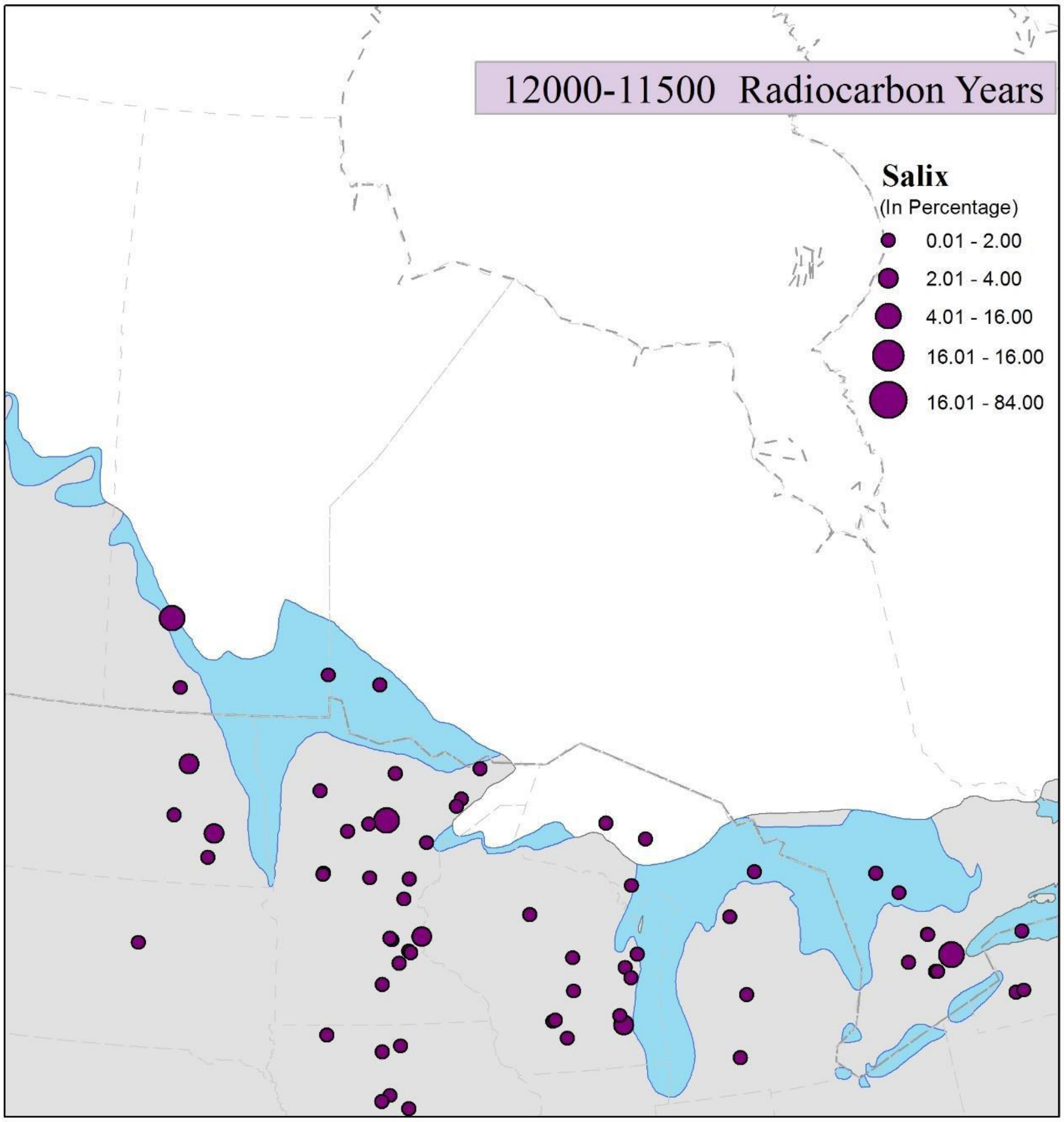

10250-10000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00


10500-10250 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

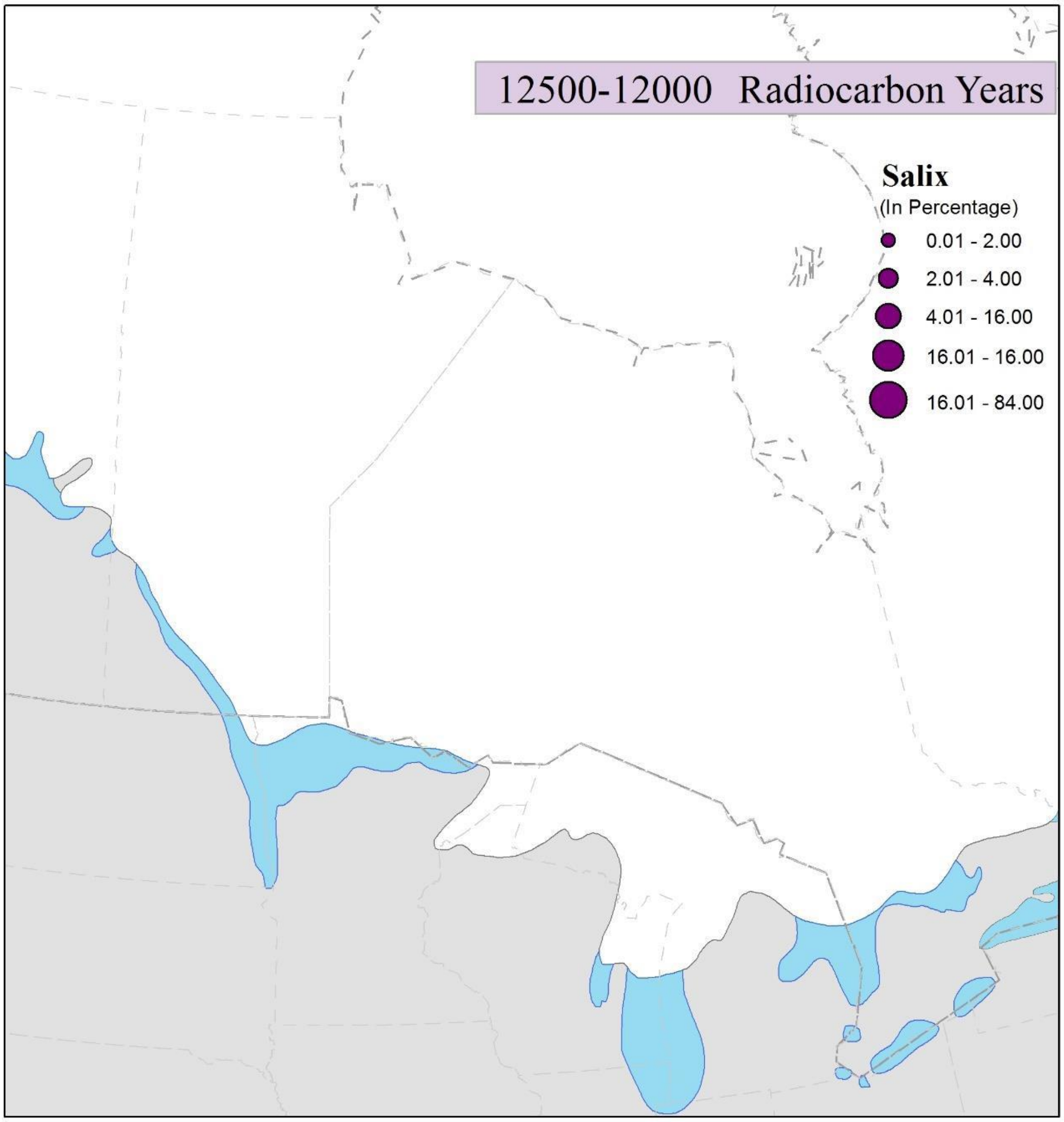

10750-10500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

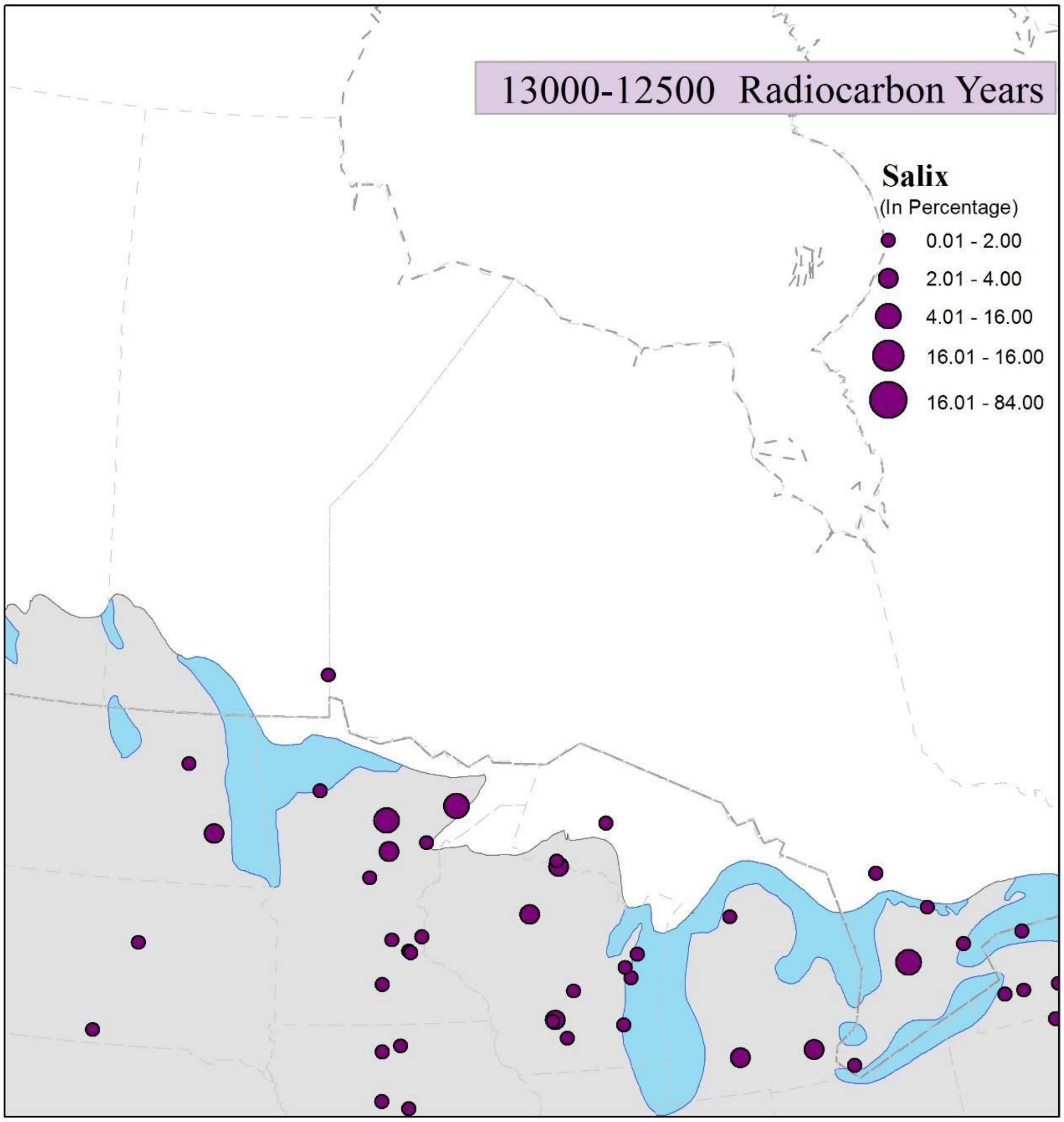

11000-10750 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

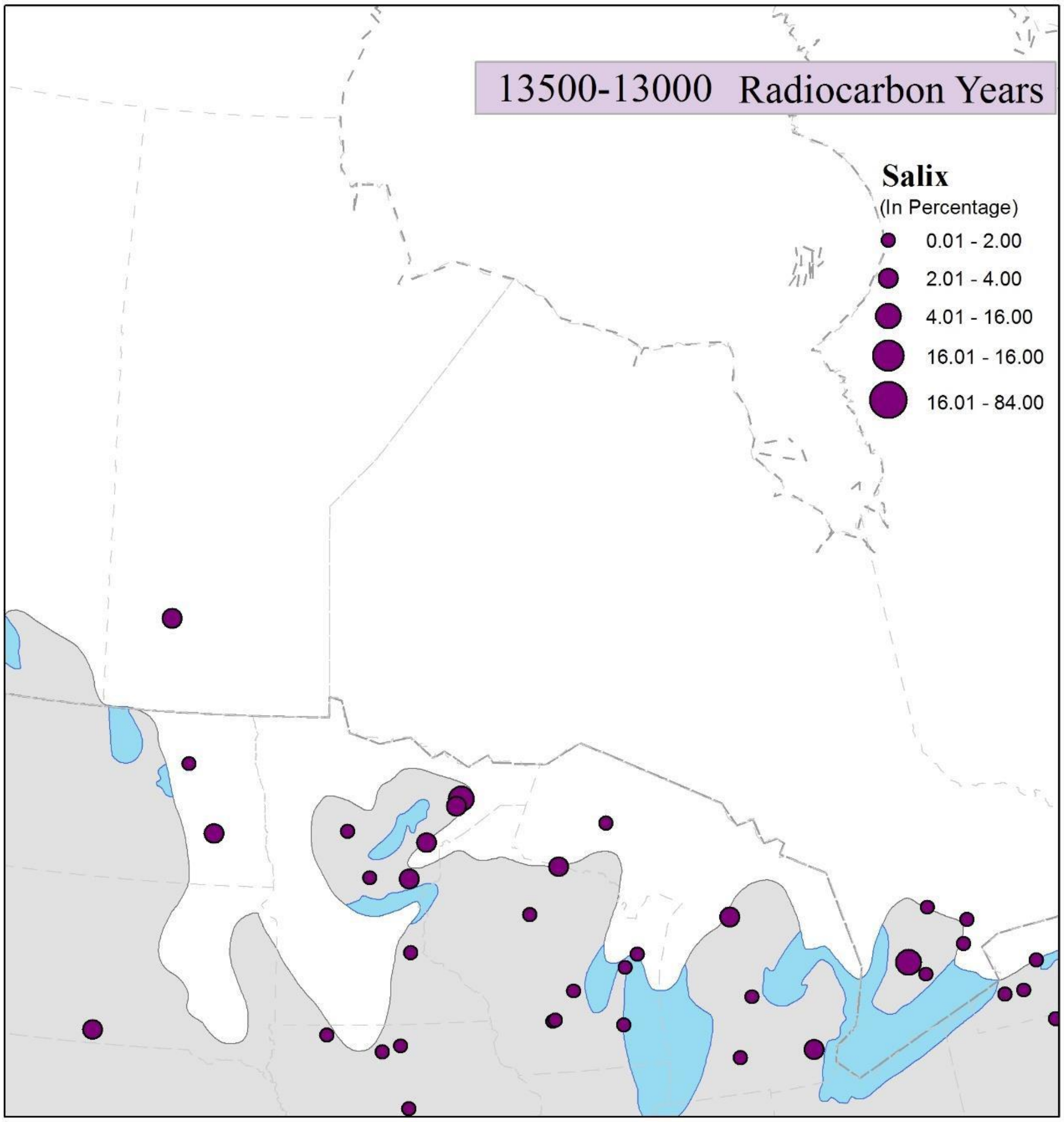

11500-11000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

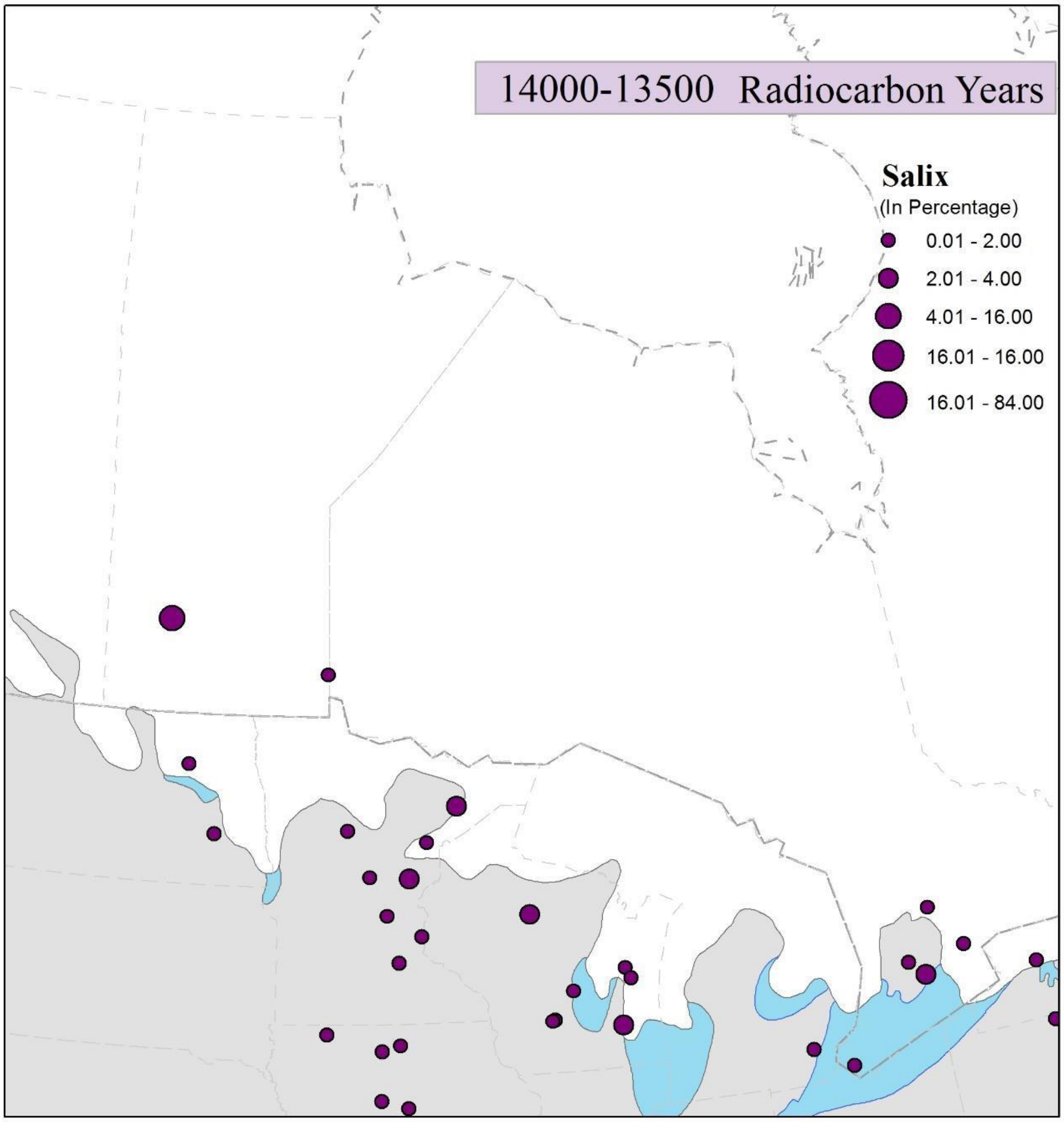


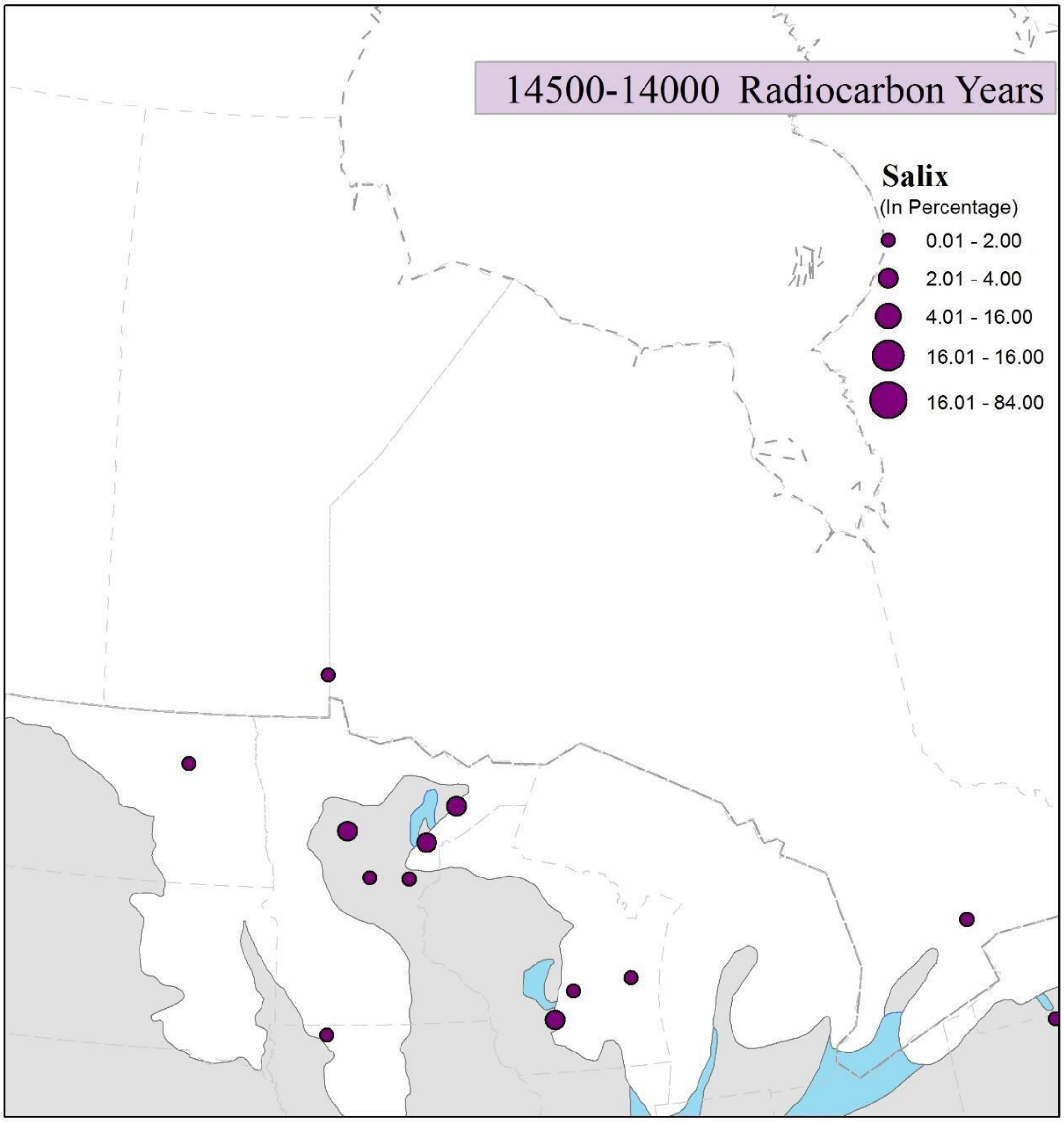
12000-11500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

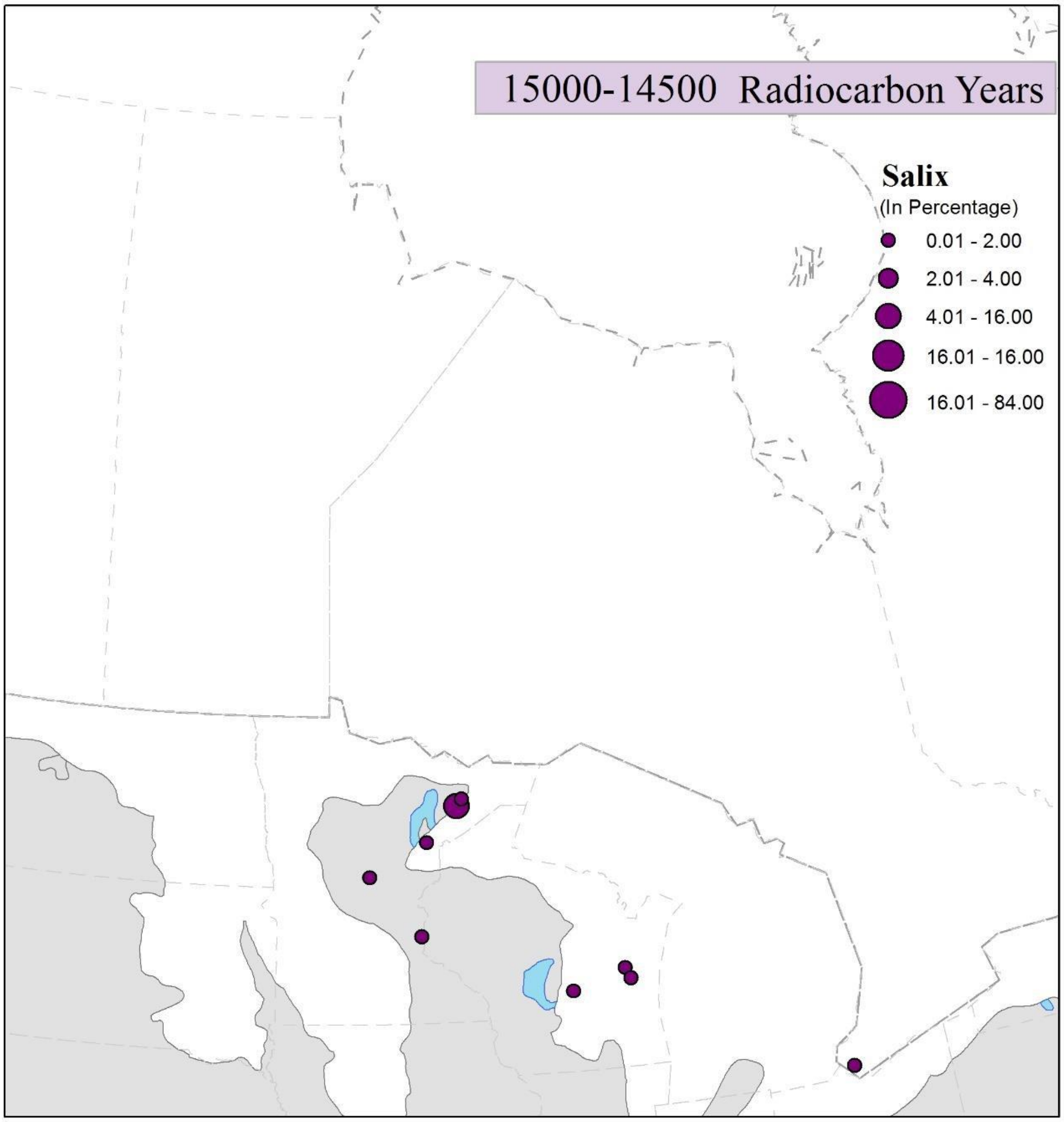

12500-12000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

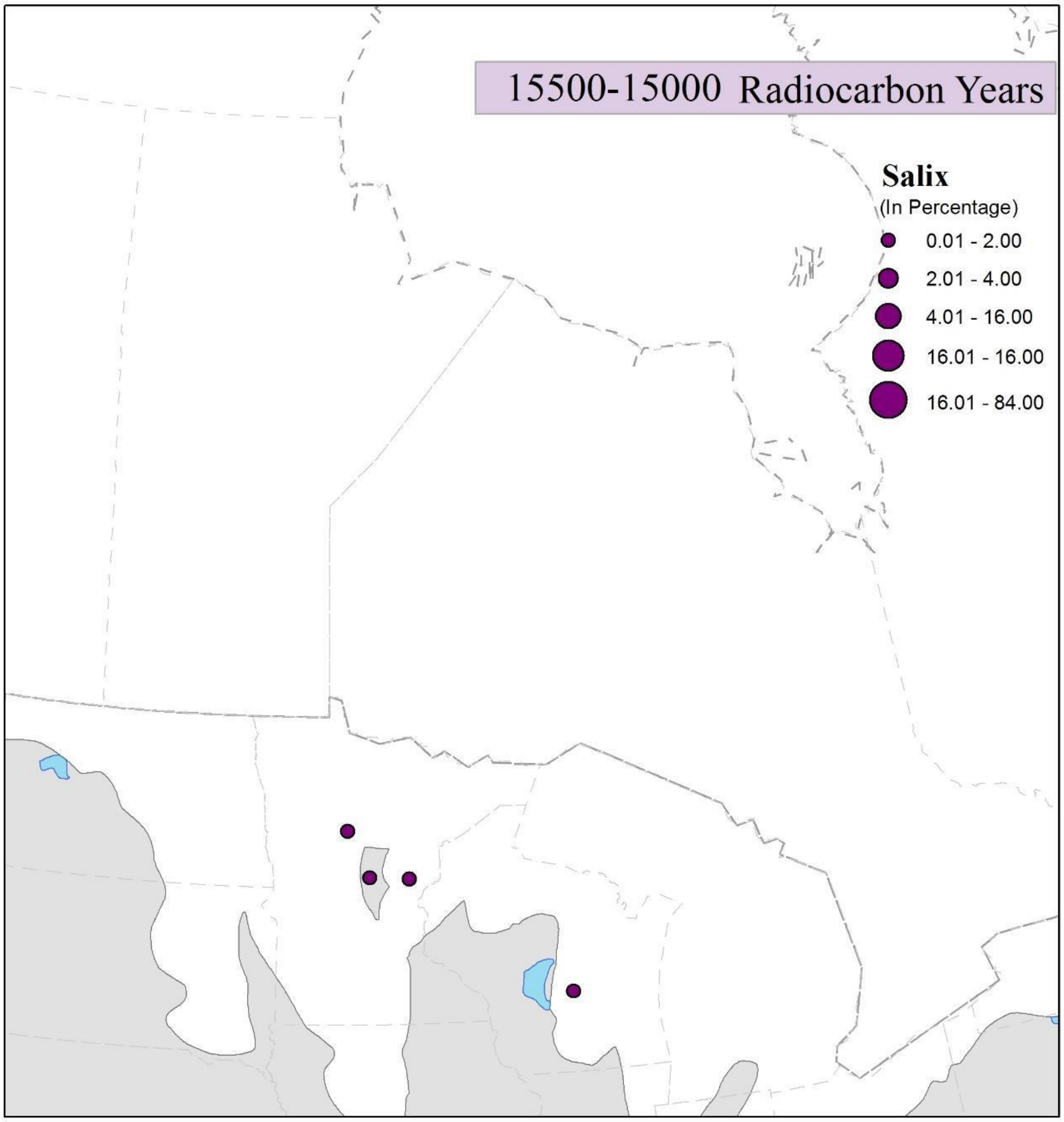

13000-12500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00


13500-13000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

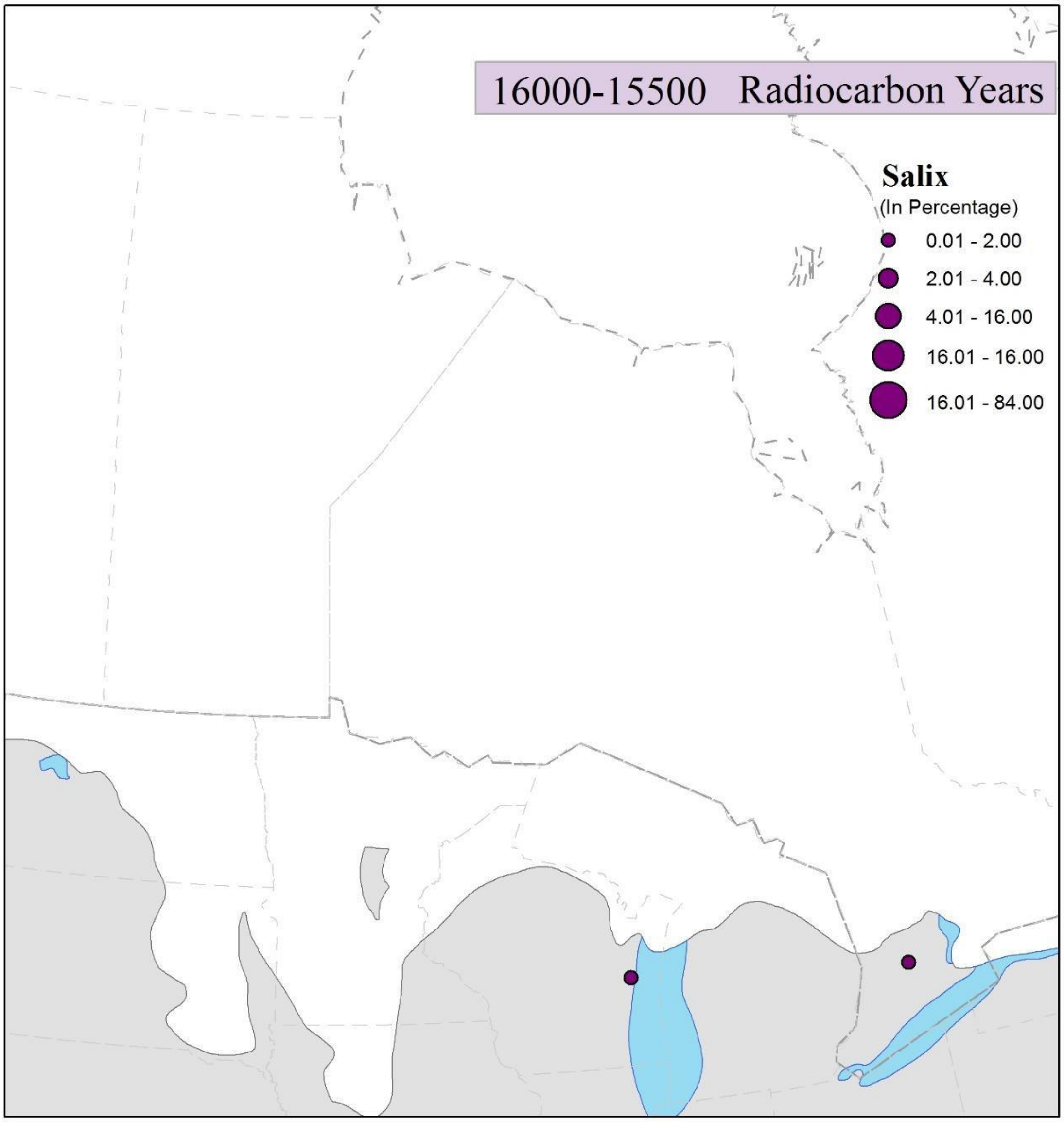

14000-13500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00


14500-14000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00


15000-14500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

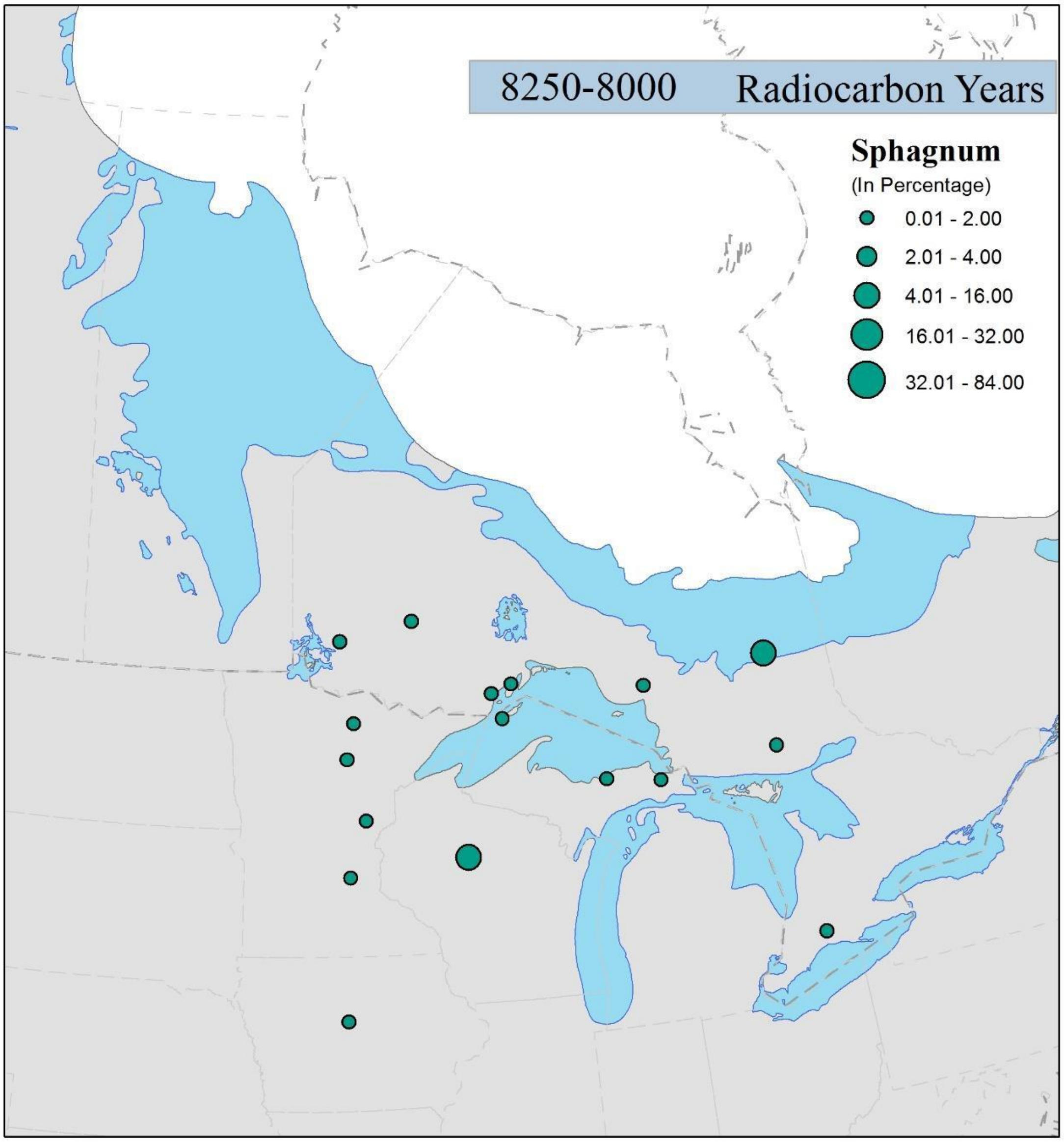


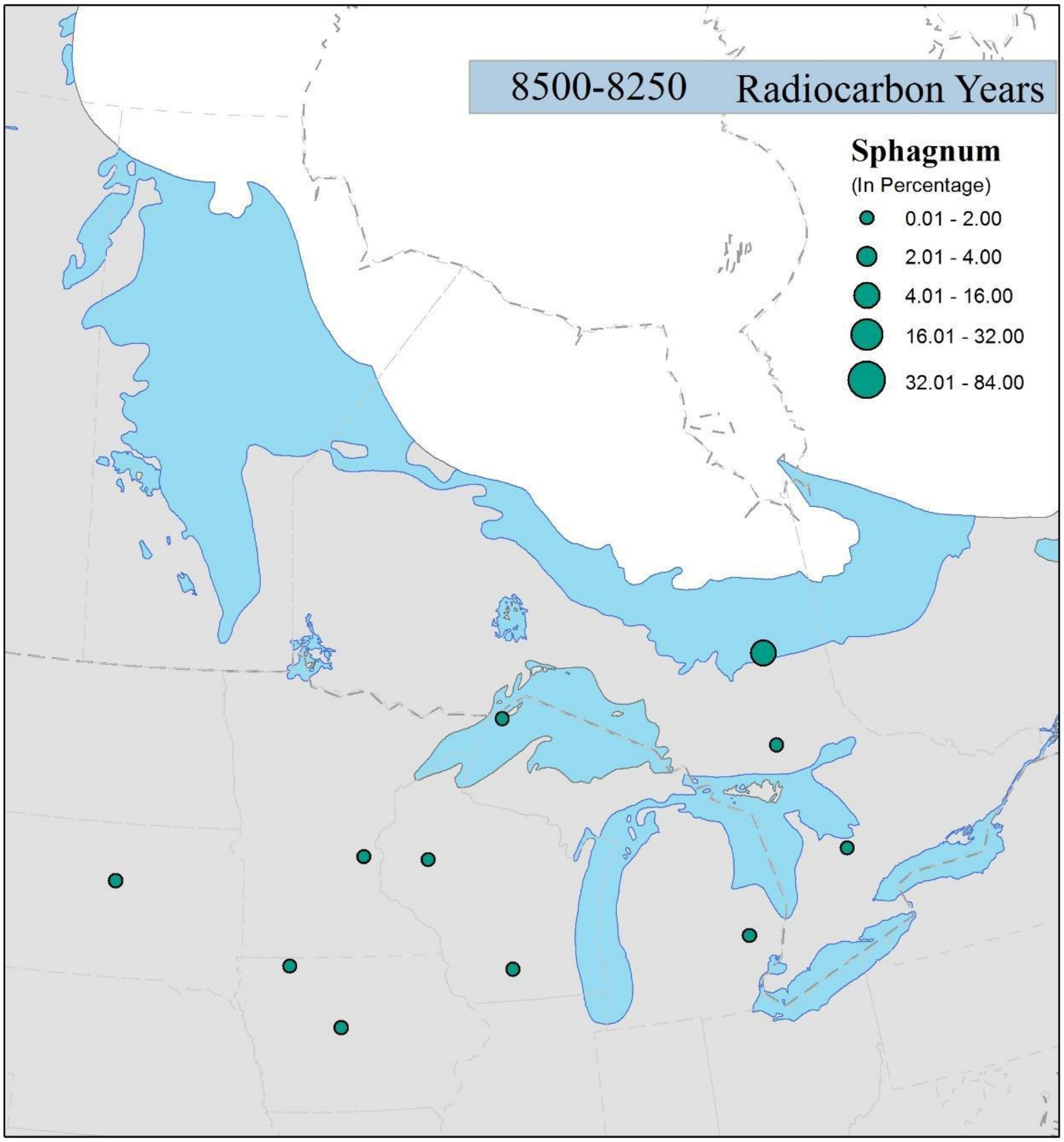
15500-15000 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00


16000-15500 Radiocarbon Years
Salix
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 16.00
16.01 - 84.00

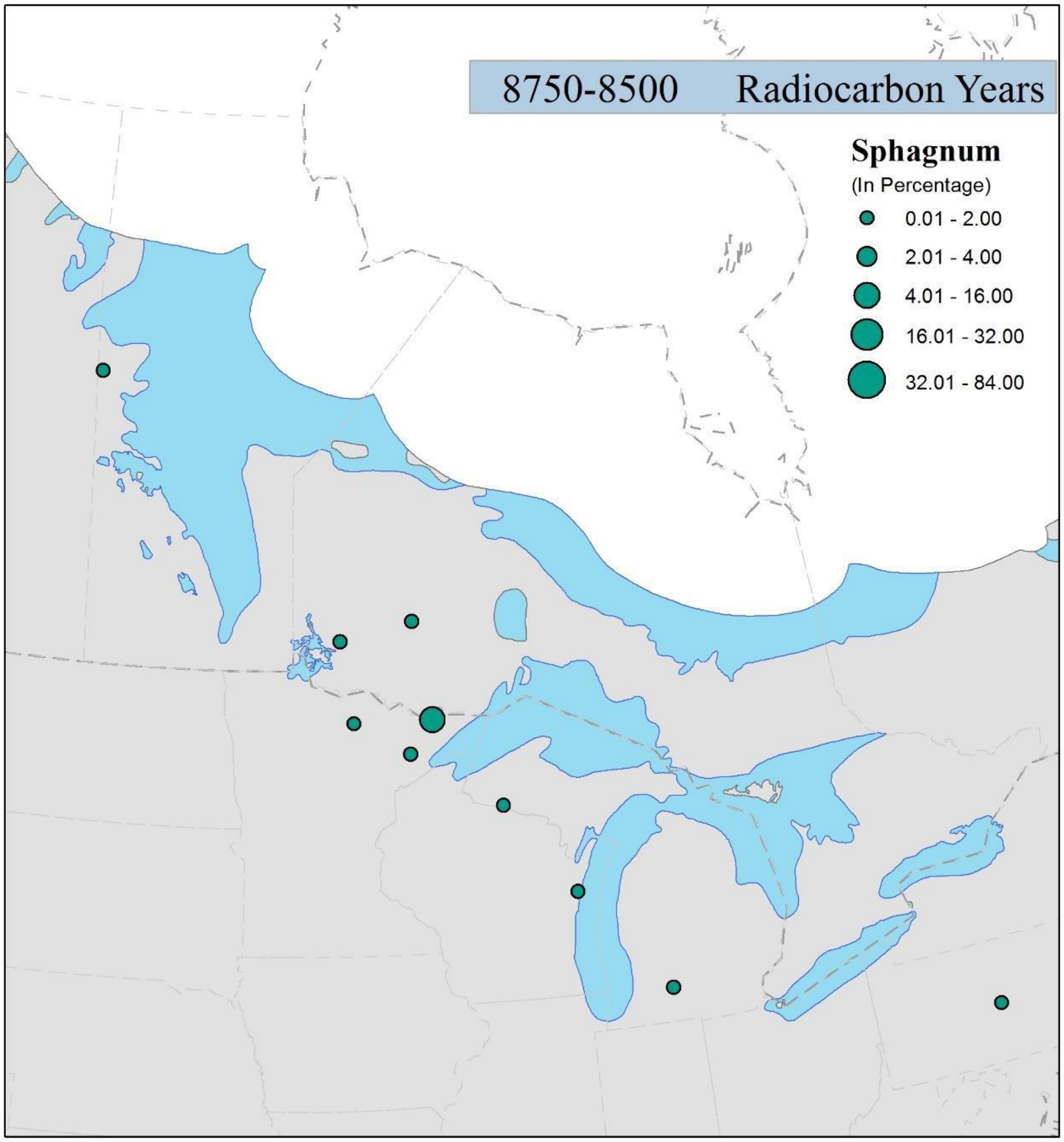
Appendix IX

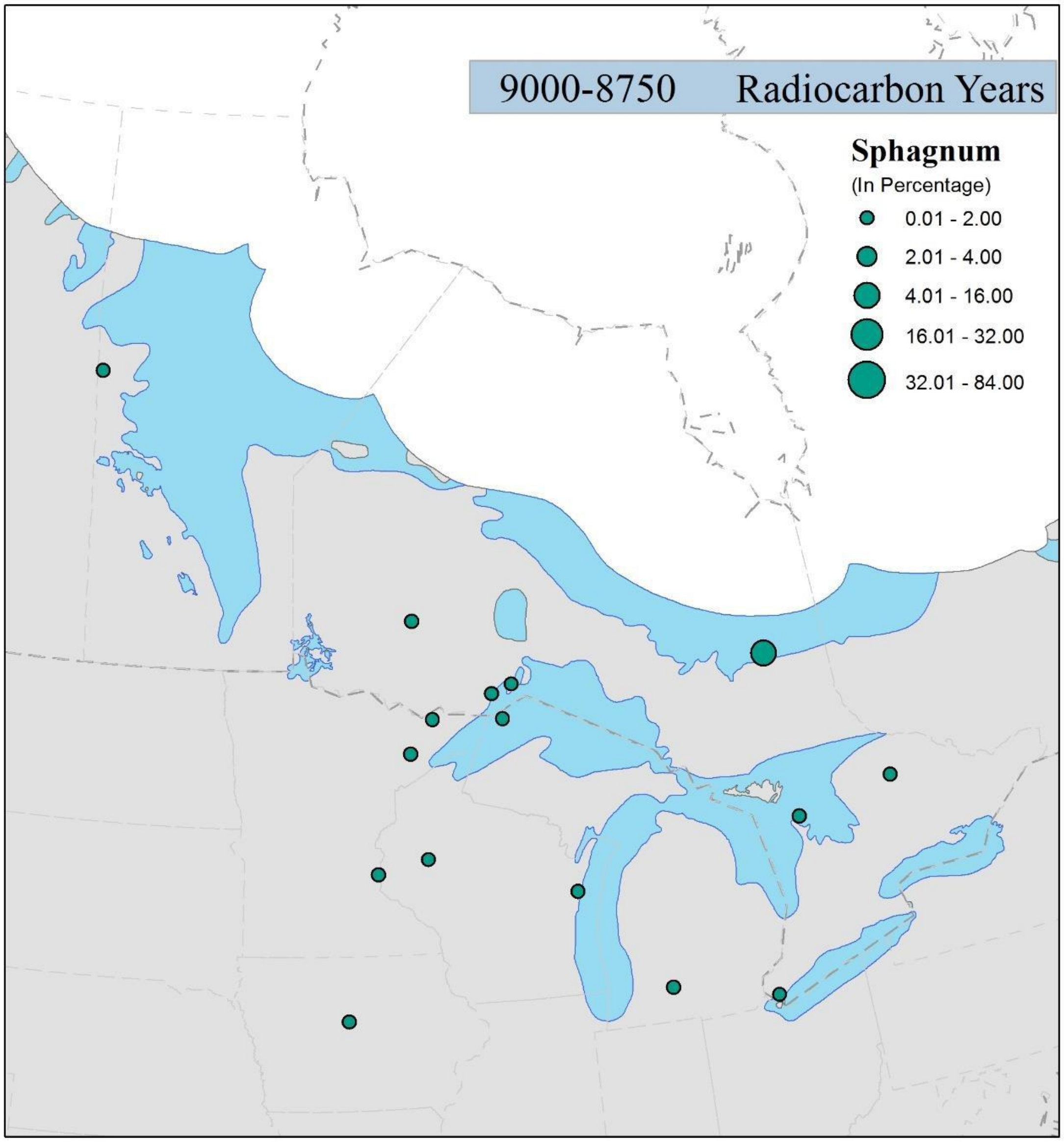
Pollen abundance of *Sphagnum*

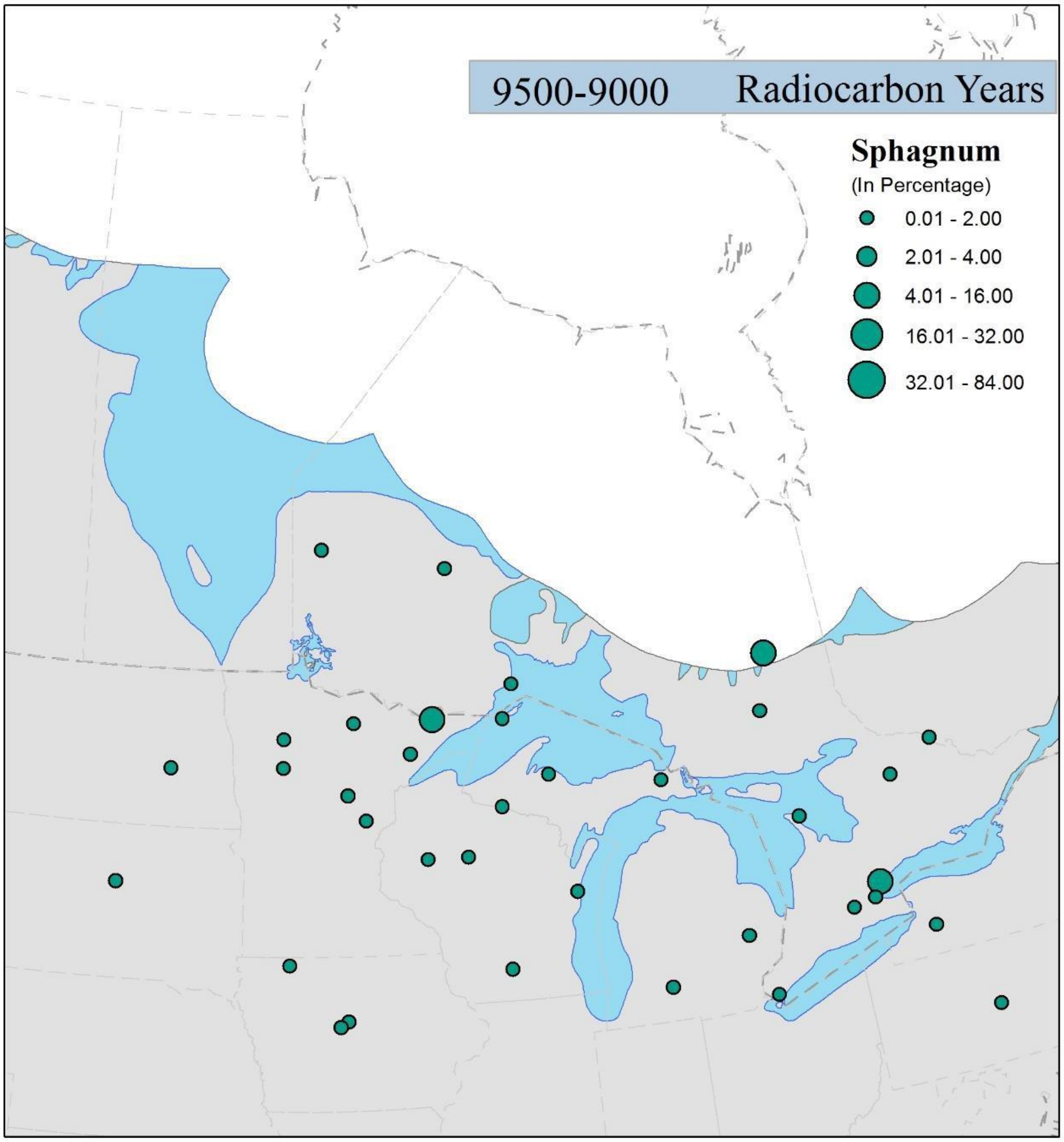

8250-8000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

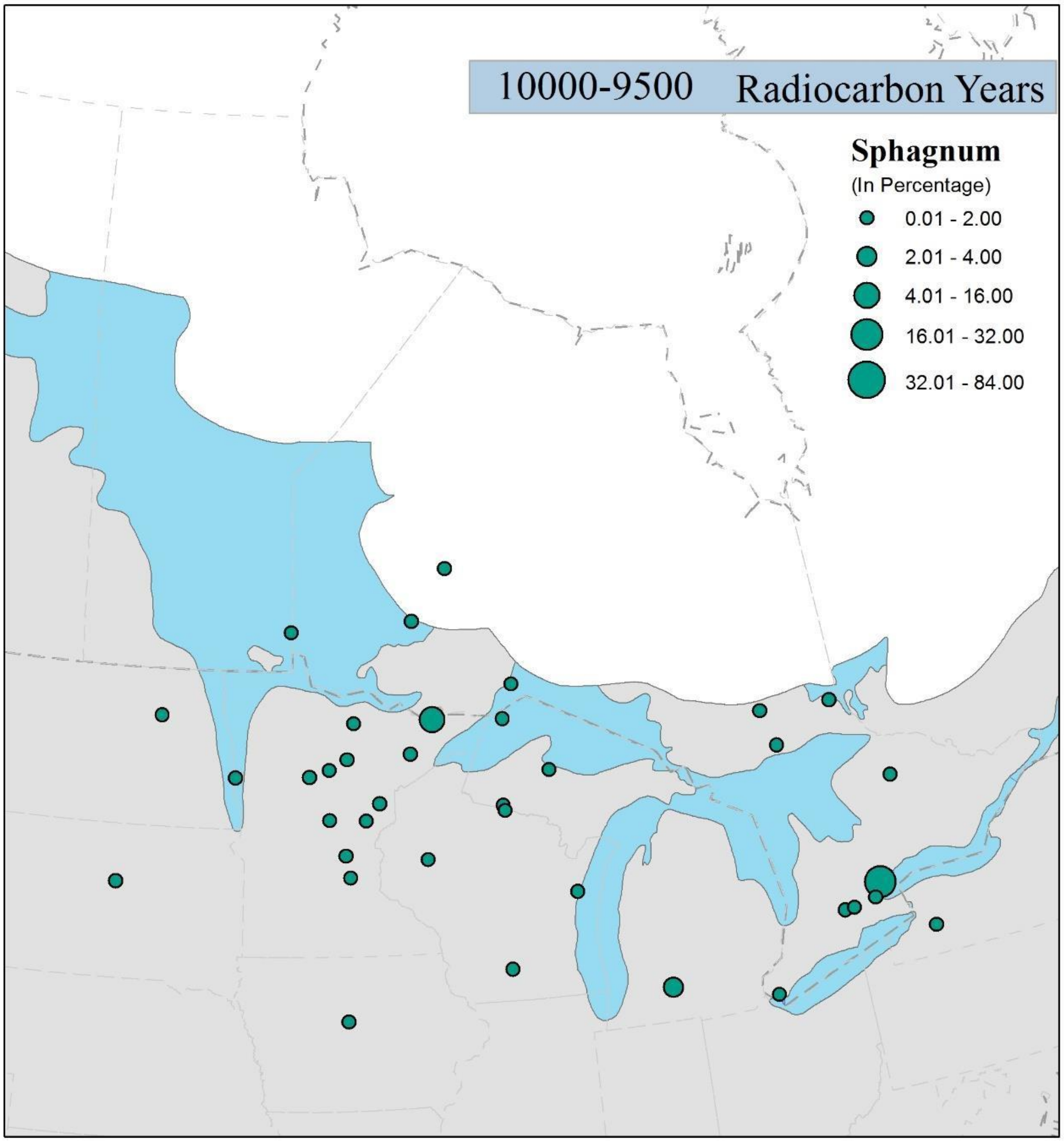


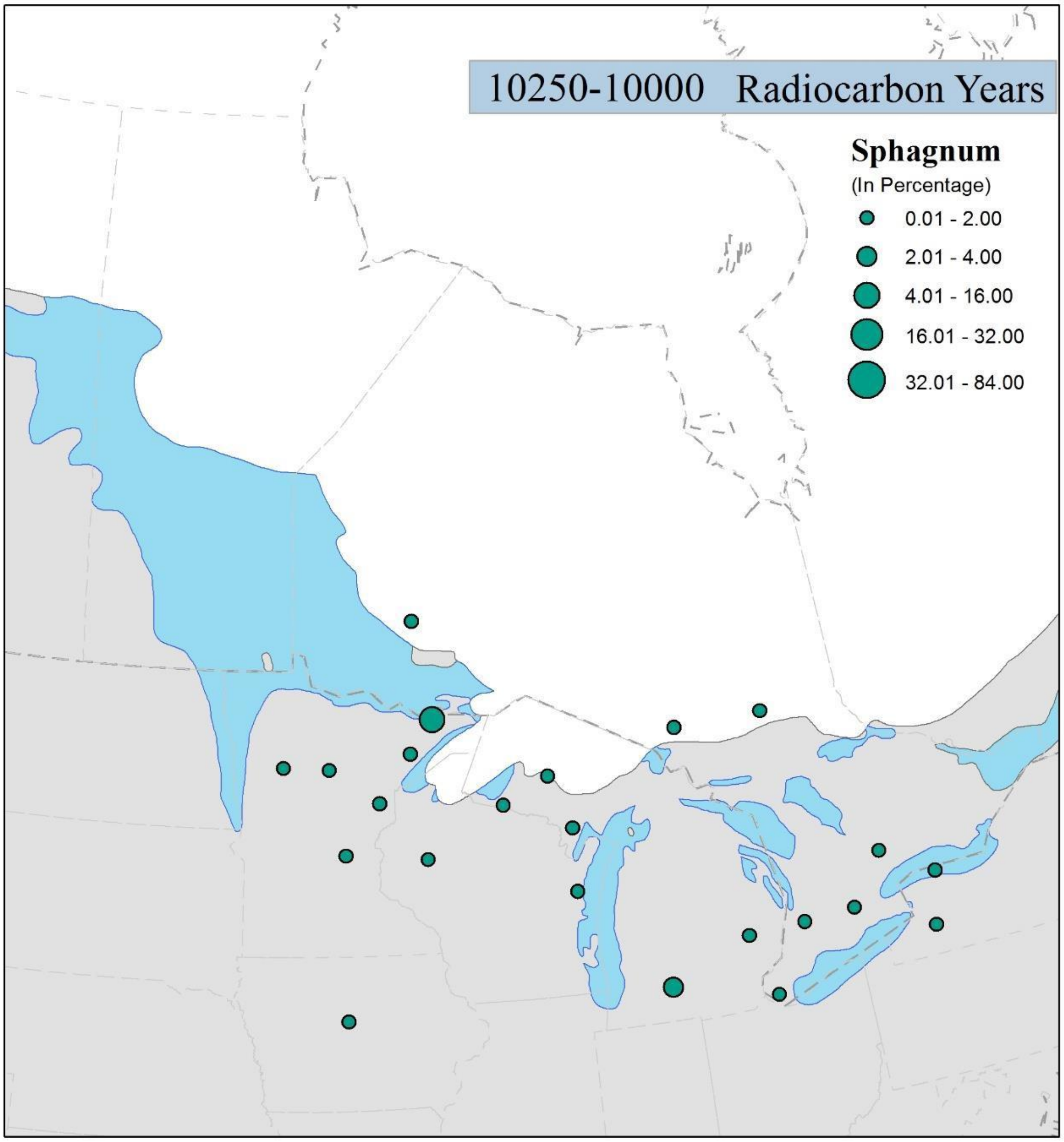
8500-8250 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

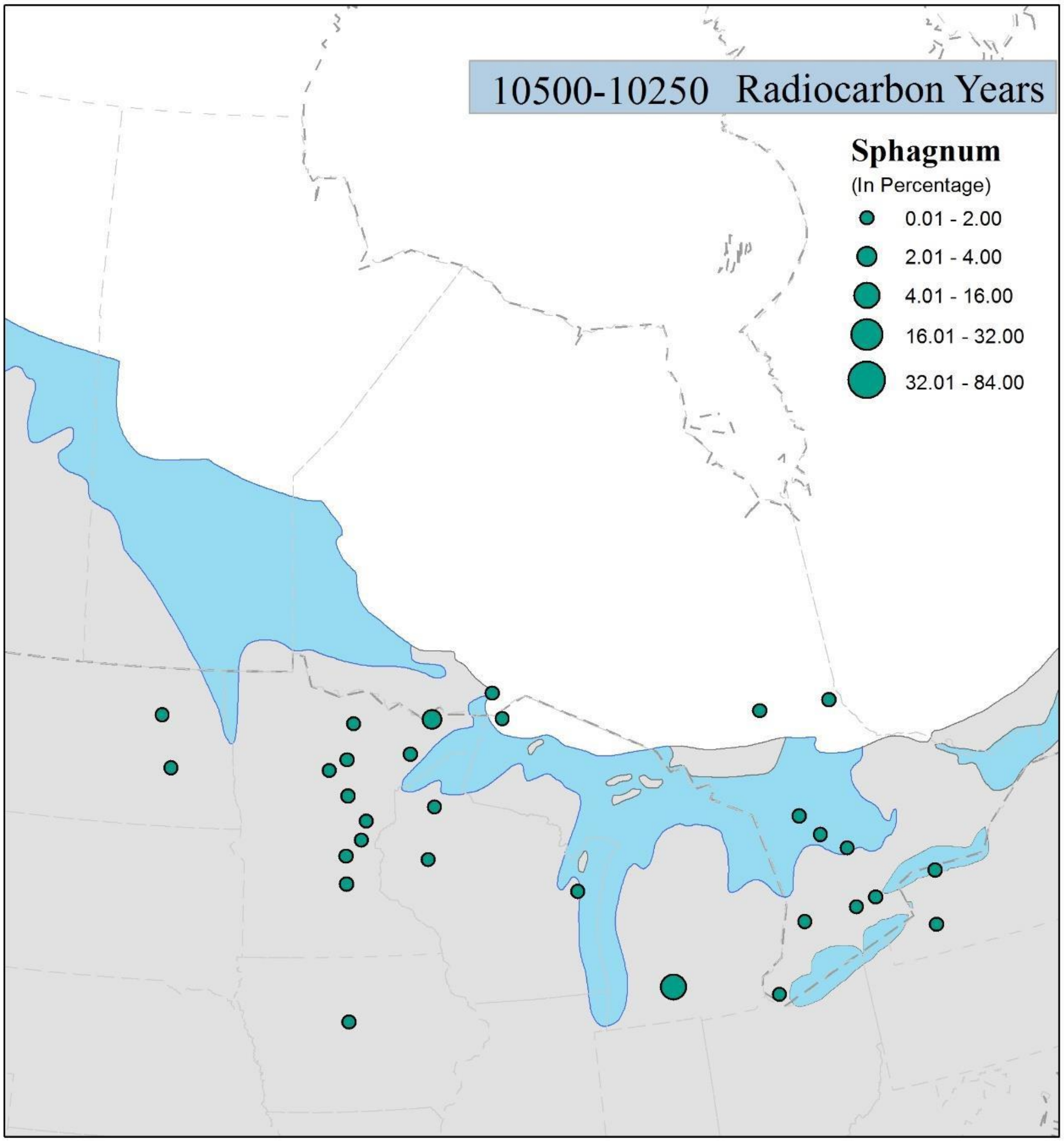

8750-8500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


9000-8750 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

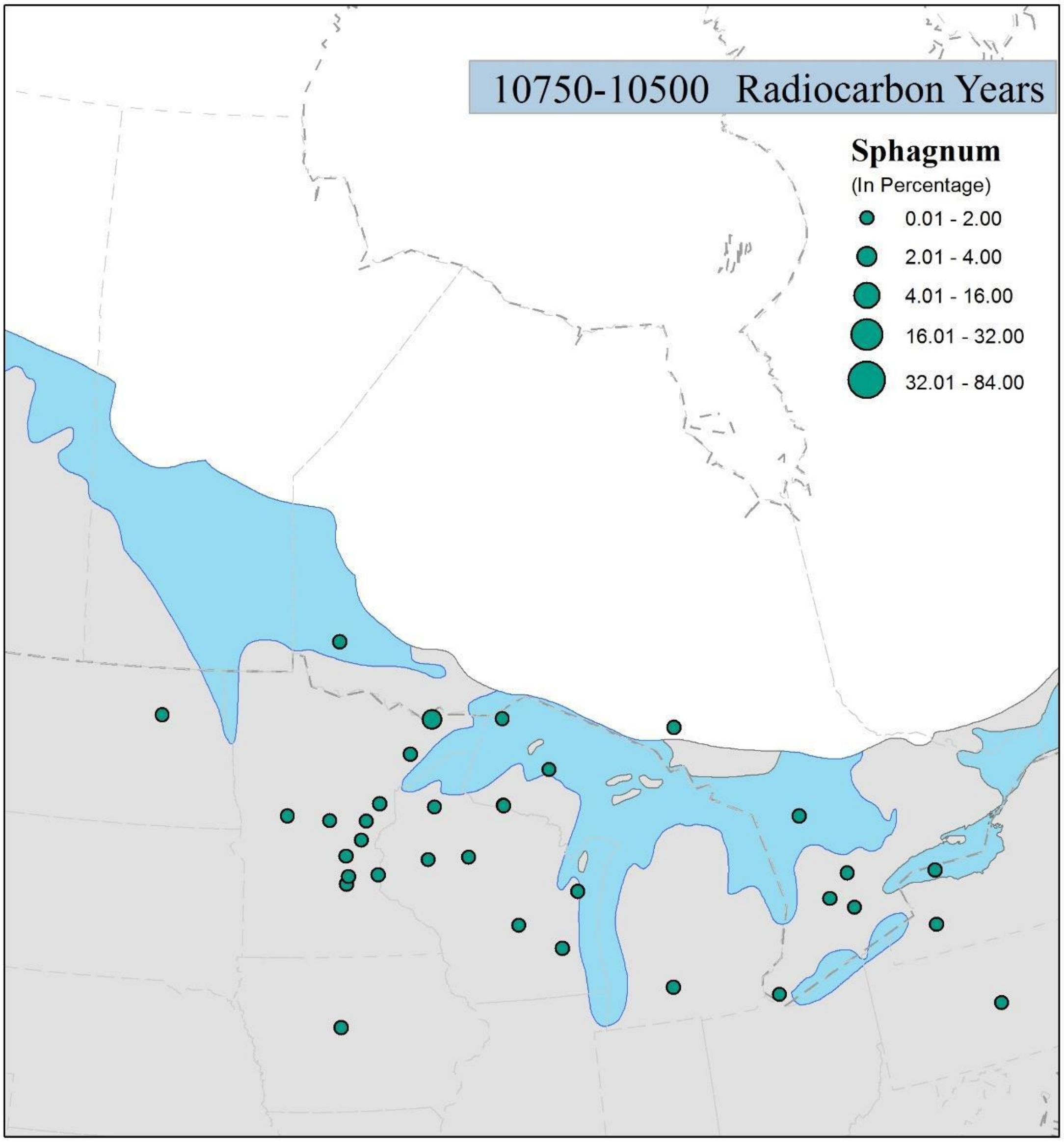

9500-9000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

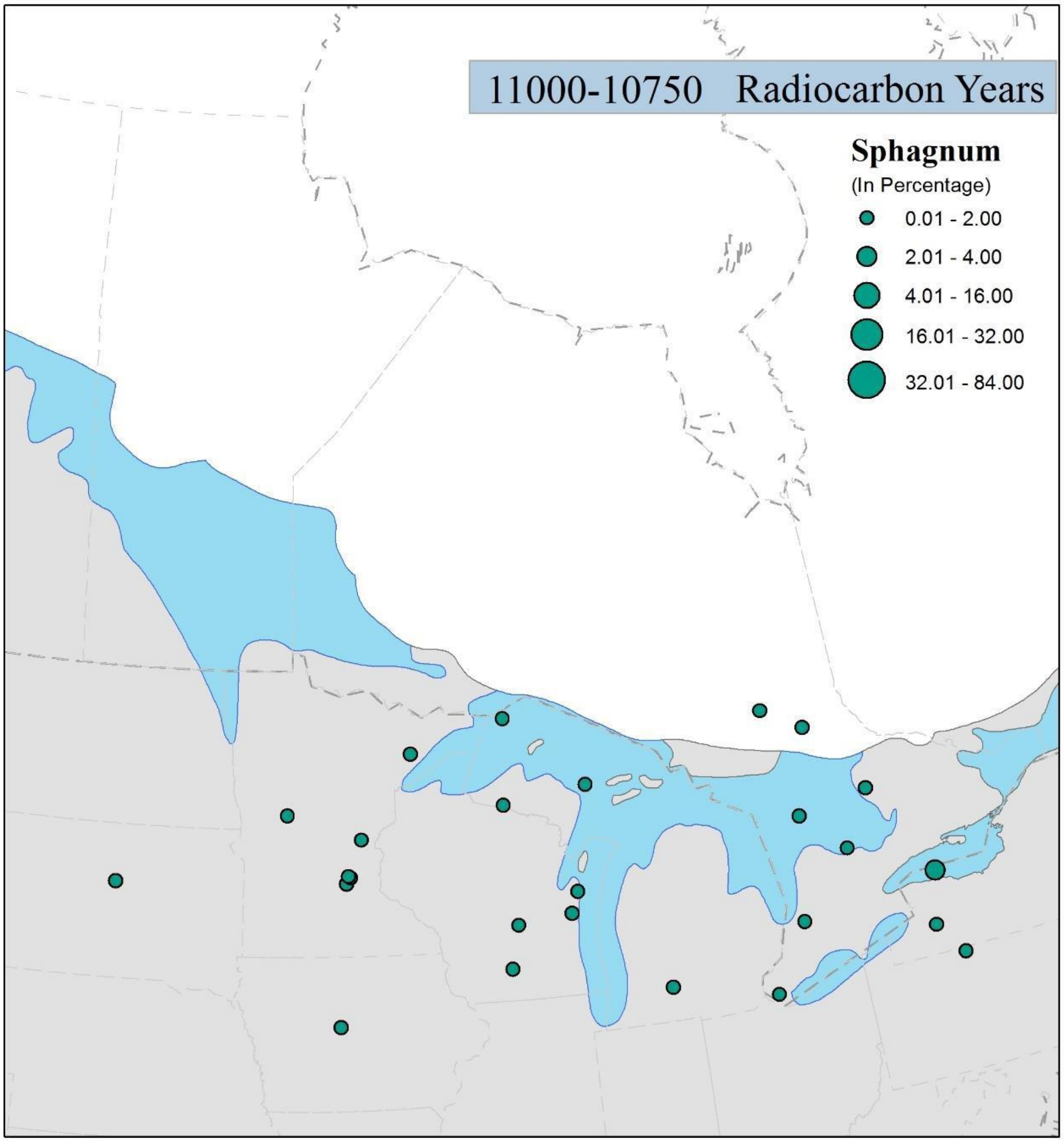

10000-9500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

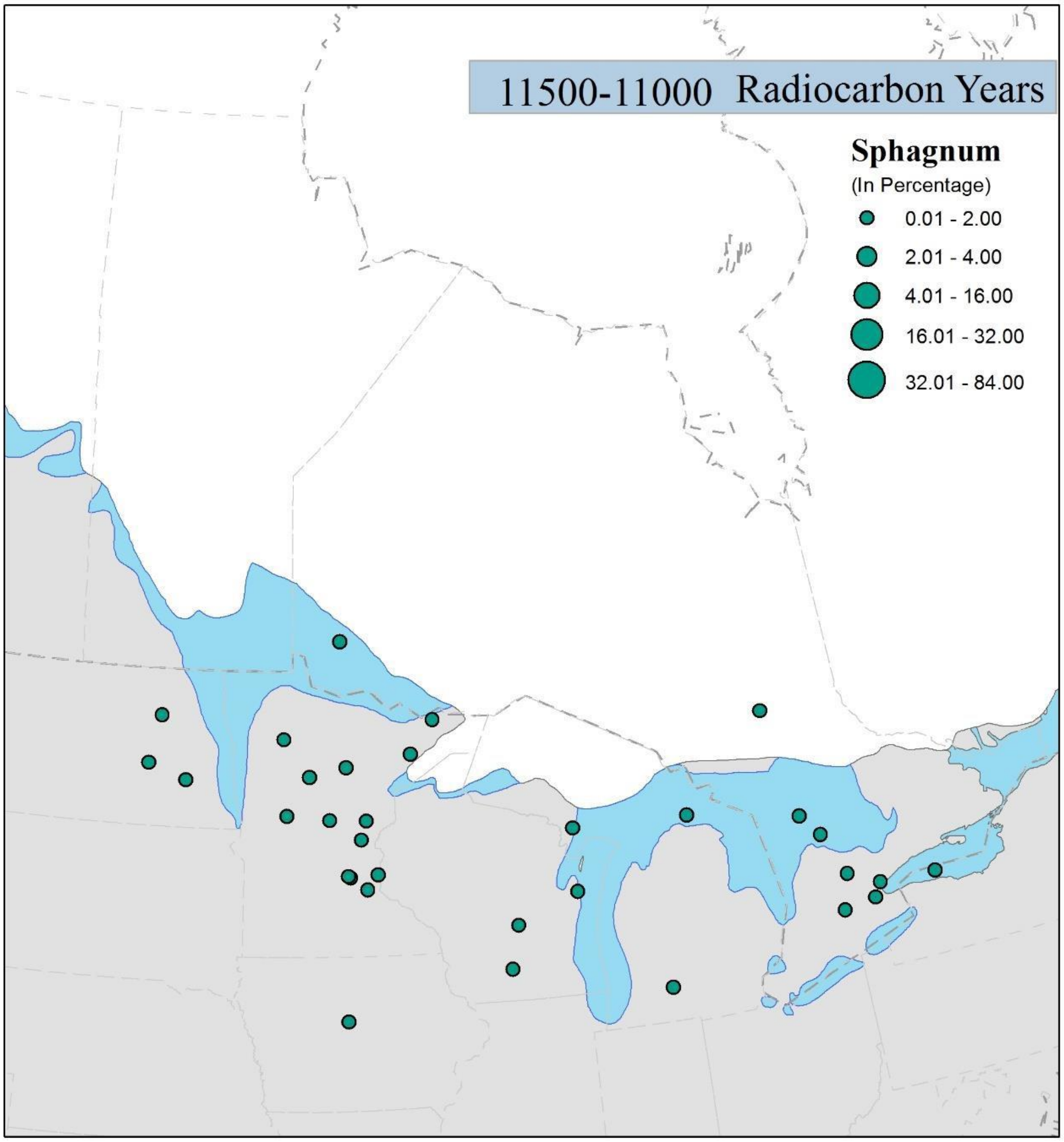

10250-10000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

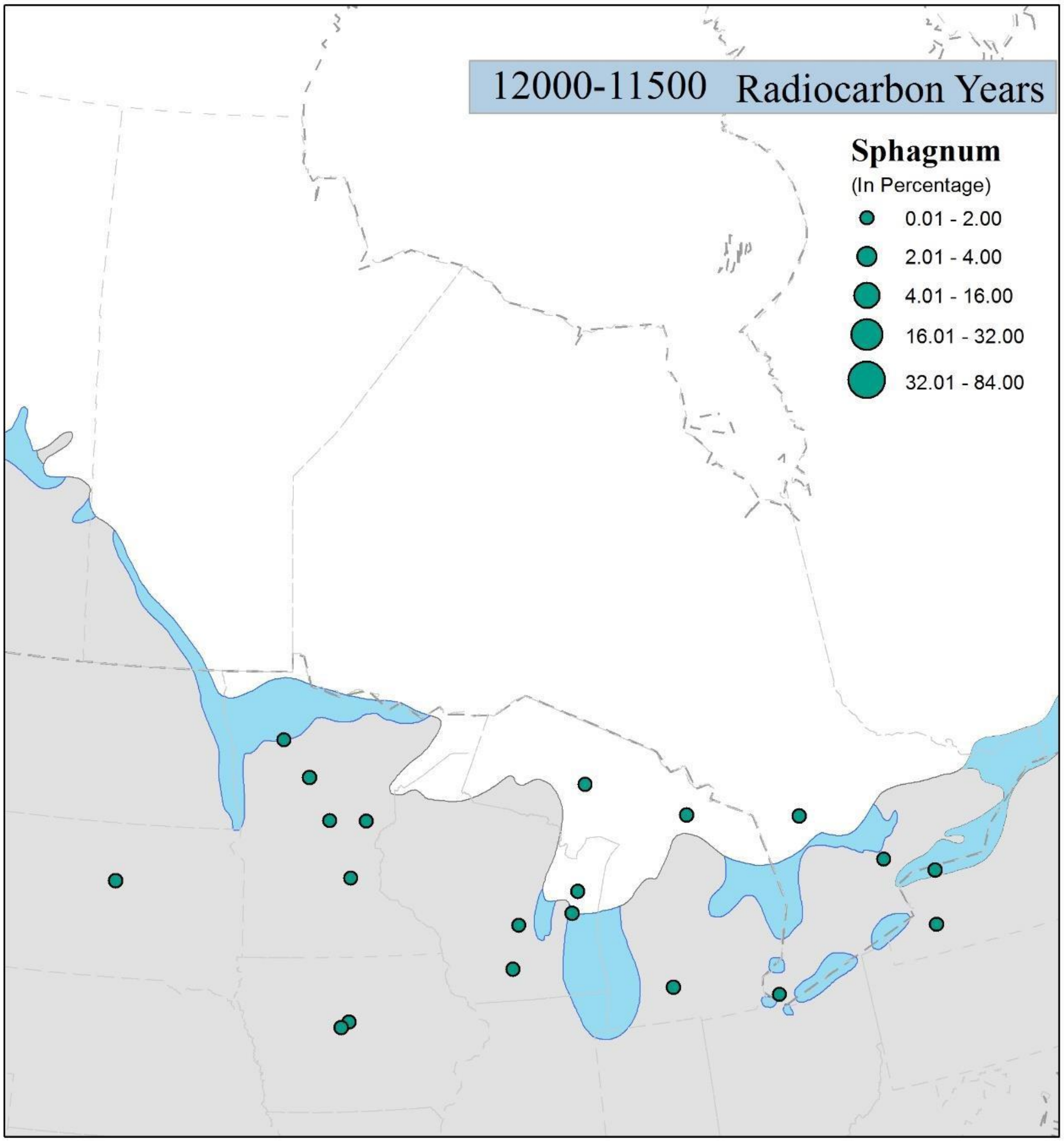


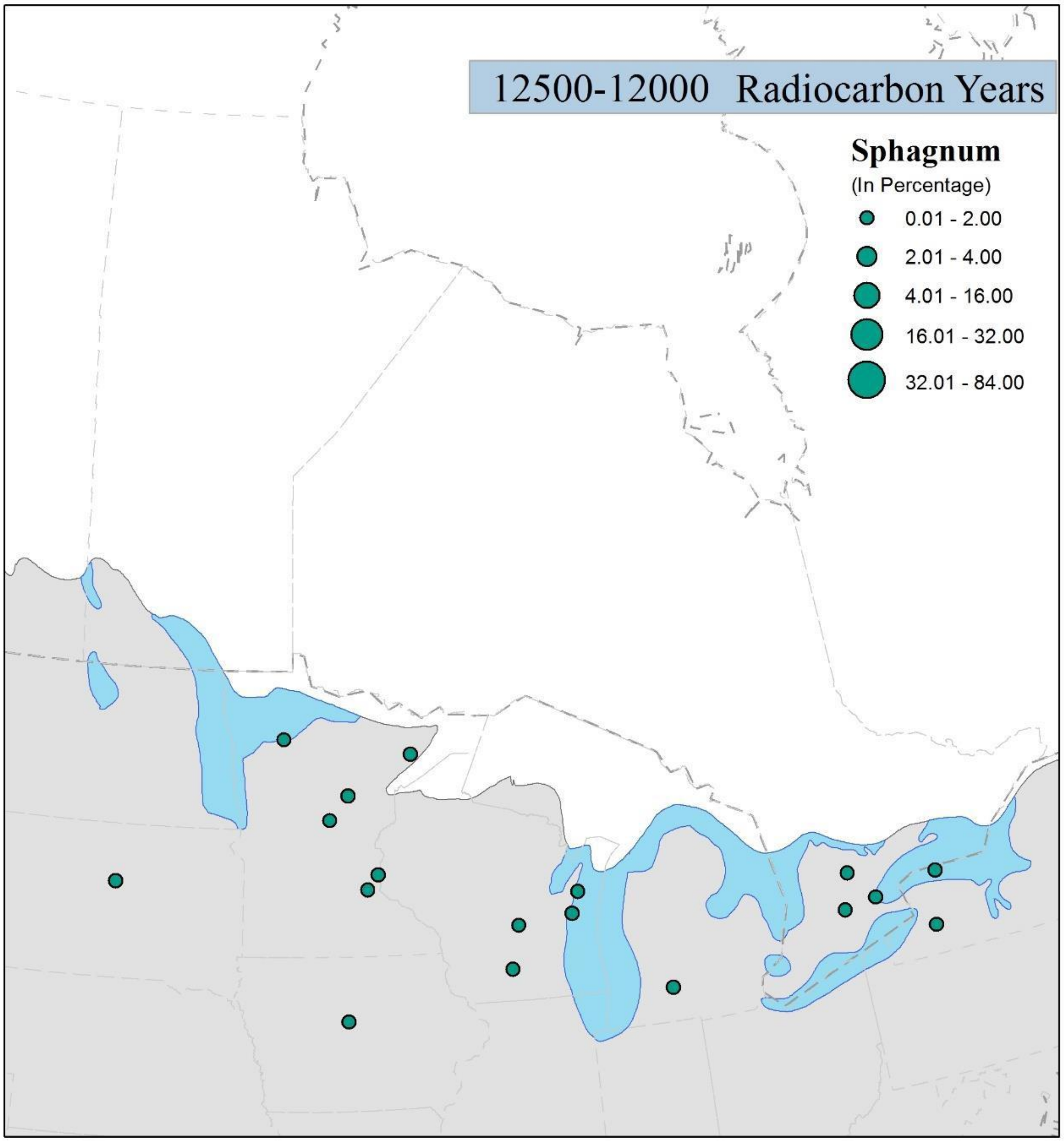
10500-10250 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


10750-10500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

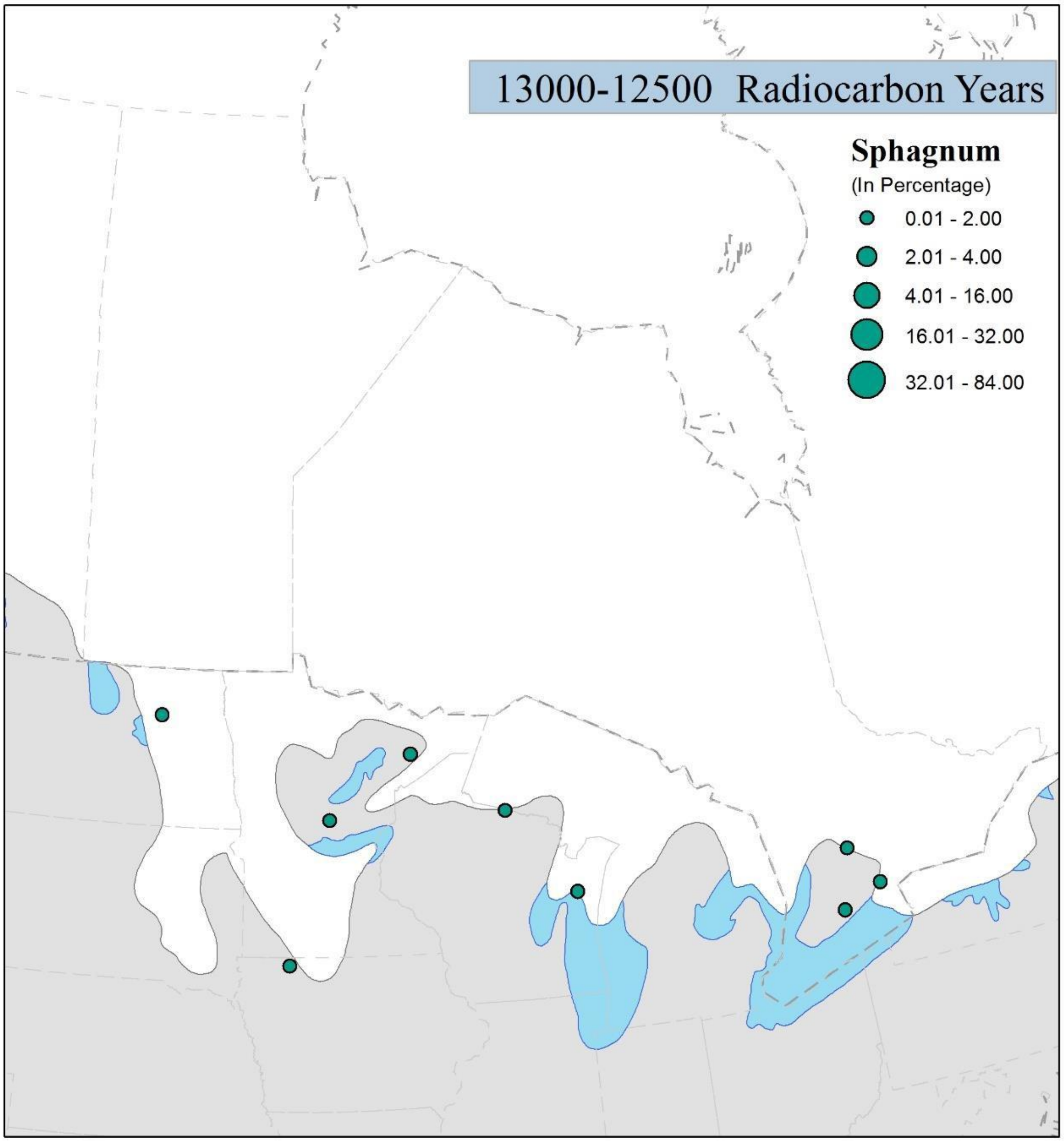

11000-10750 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


11500-11000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

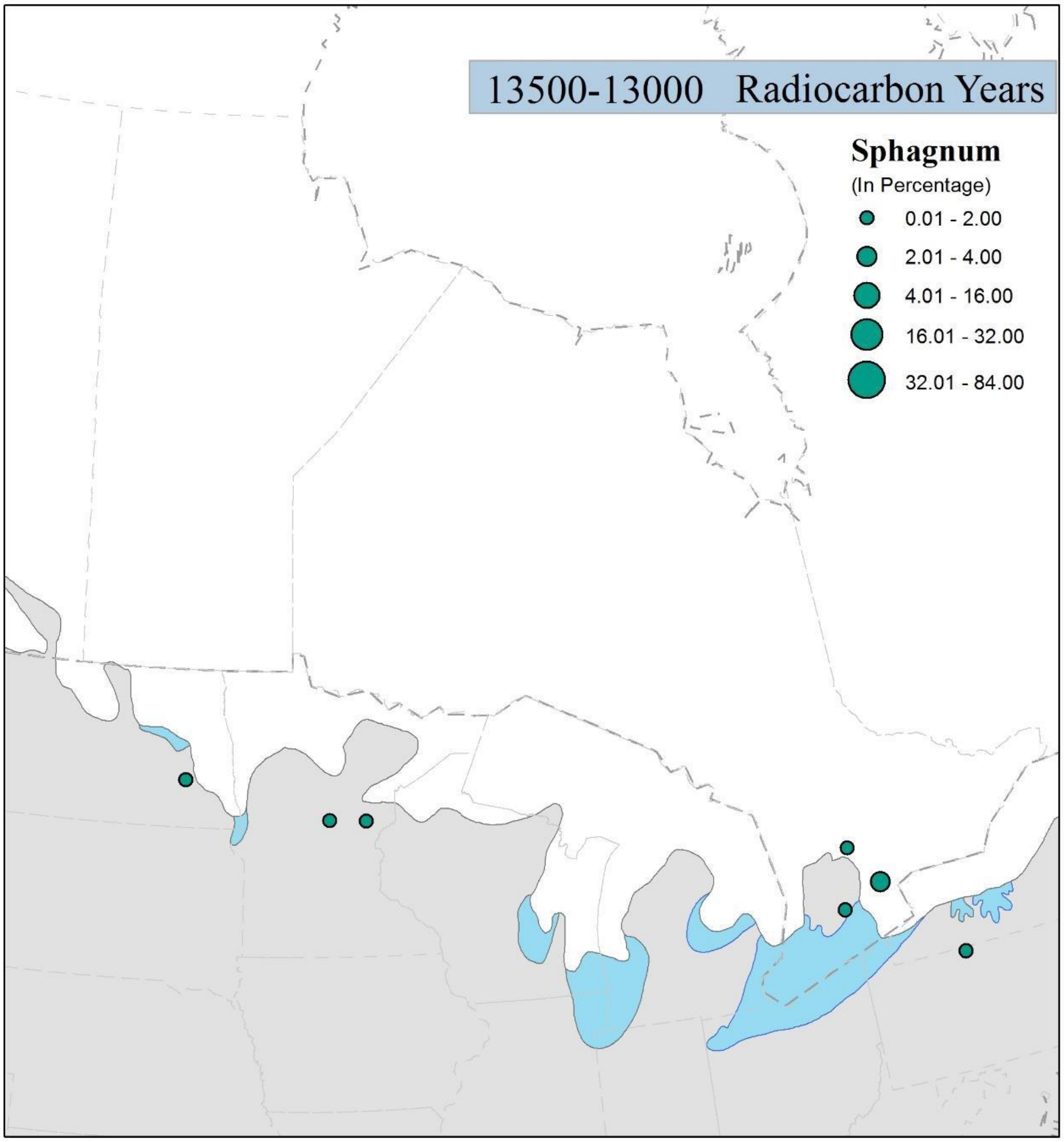

12000-11500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

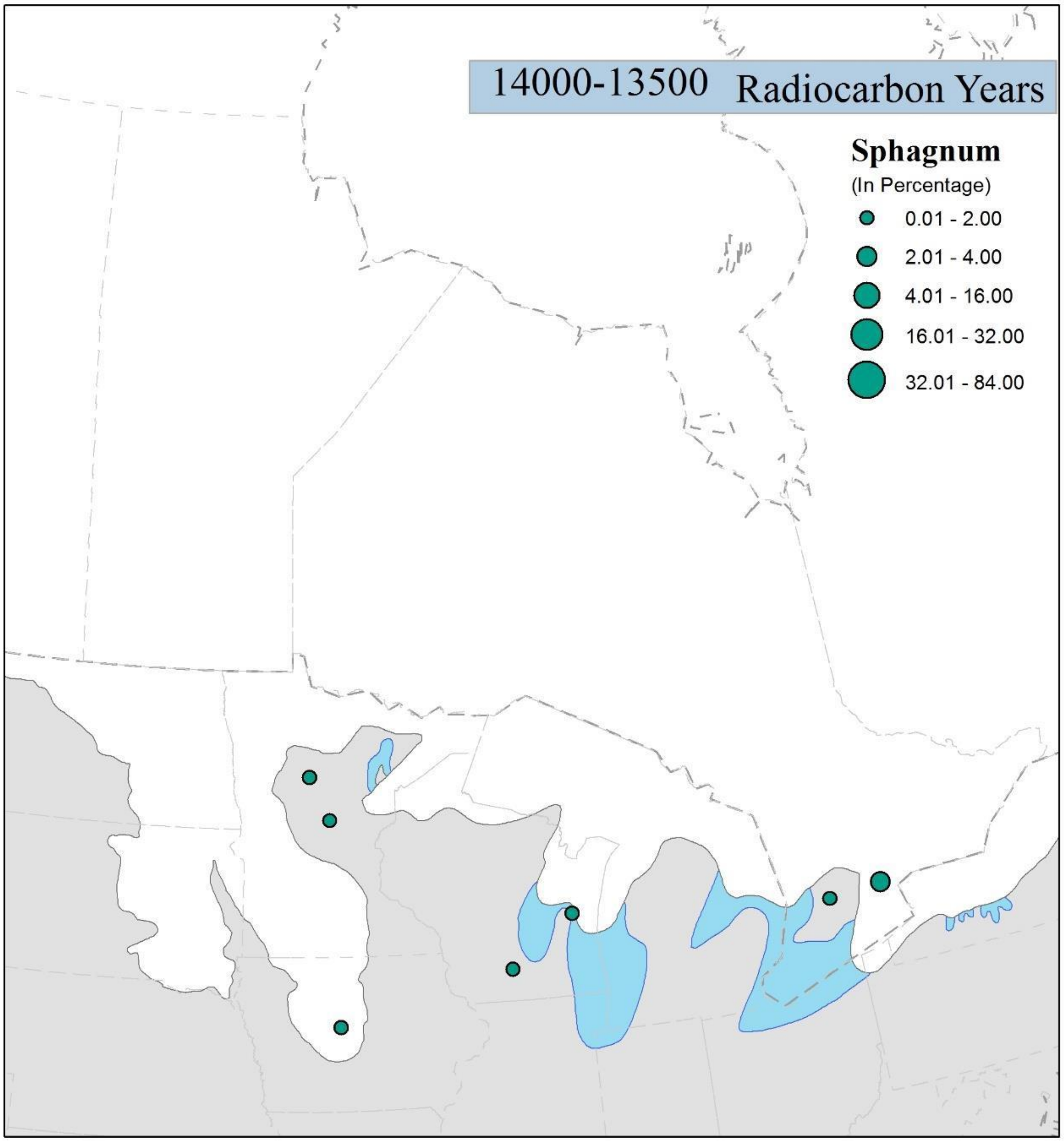


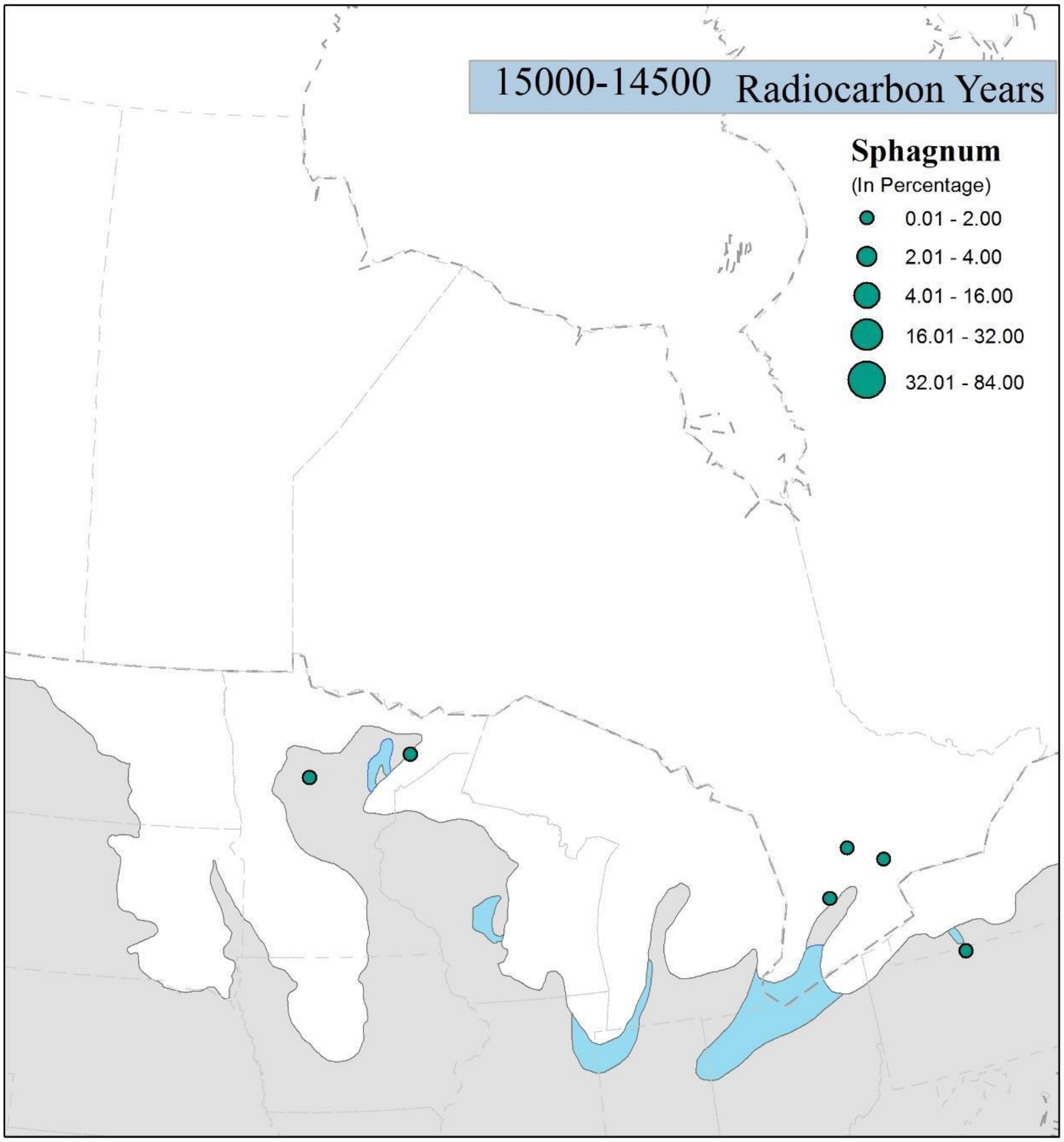
12500-12000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

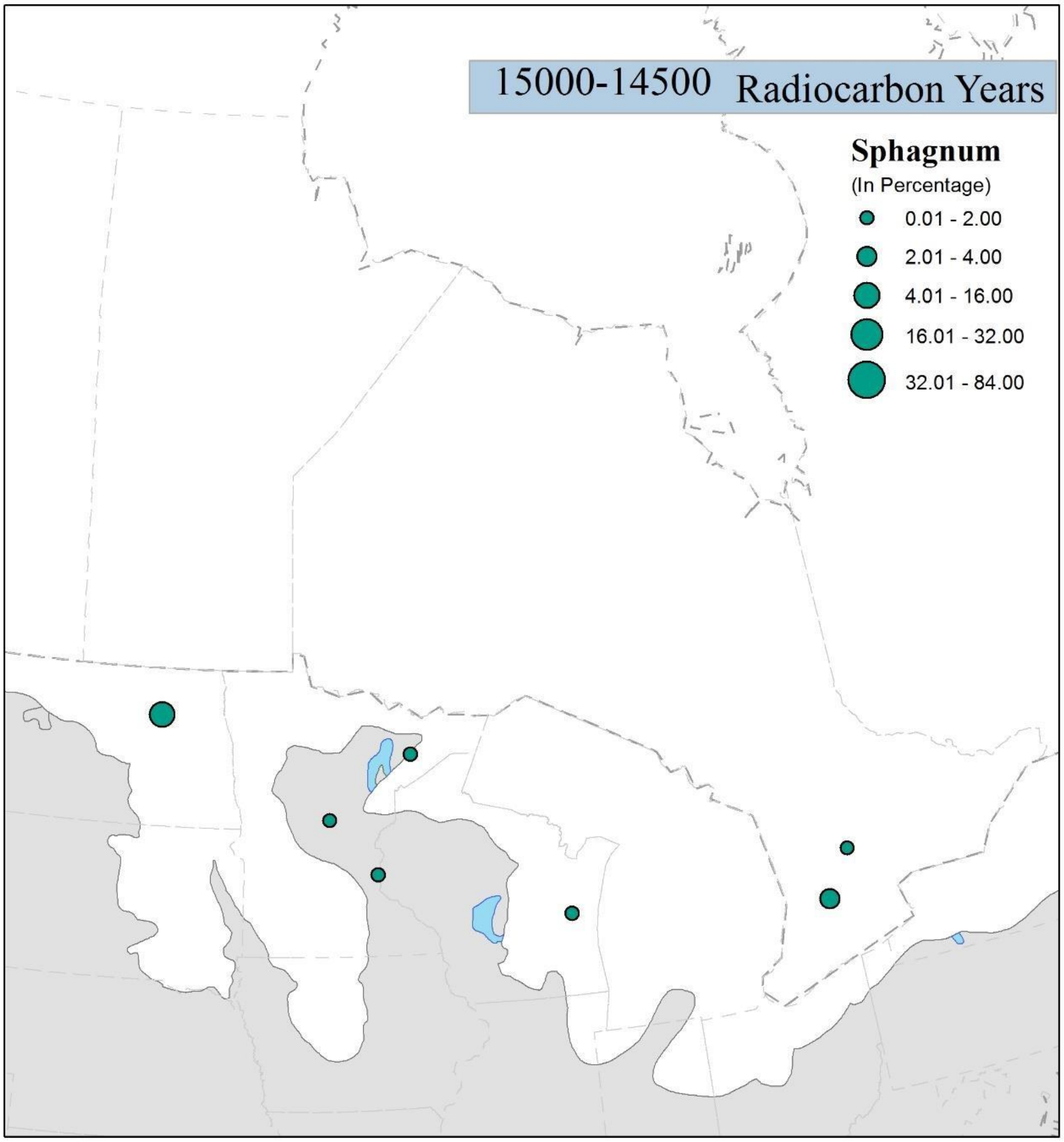


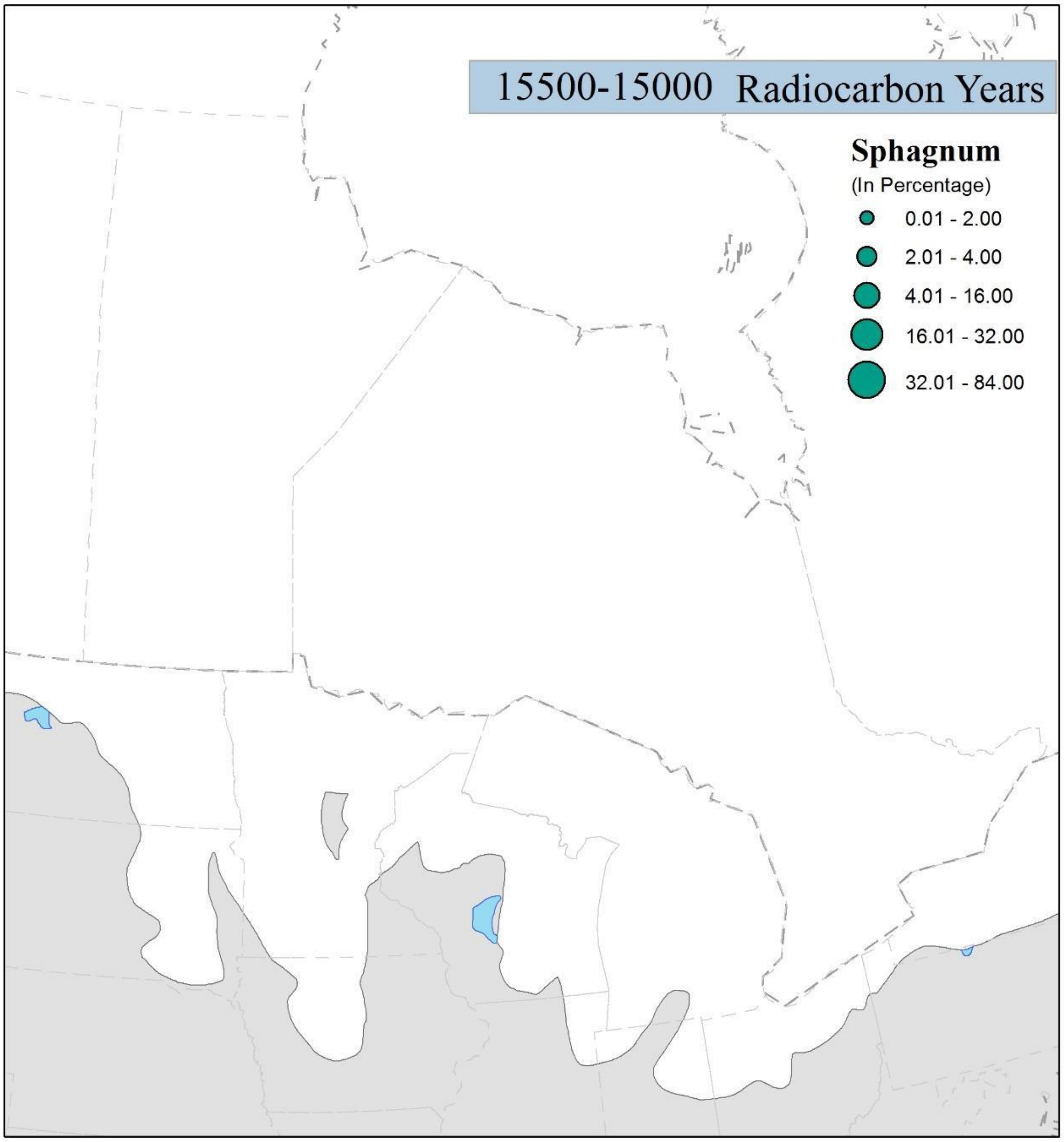
13000-12500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

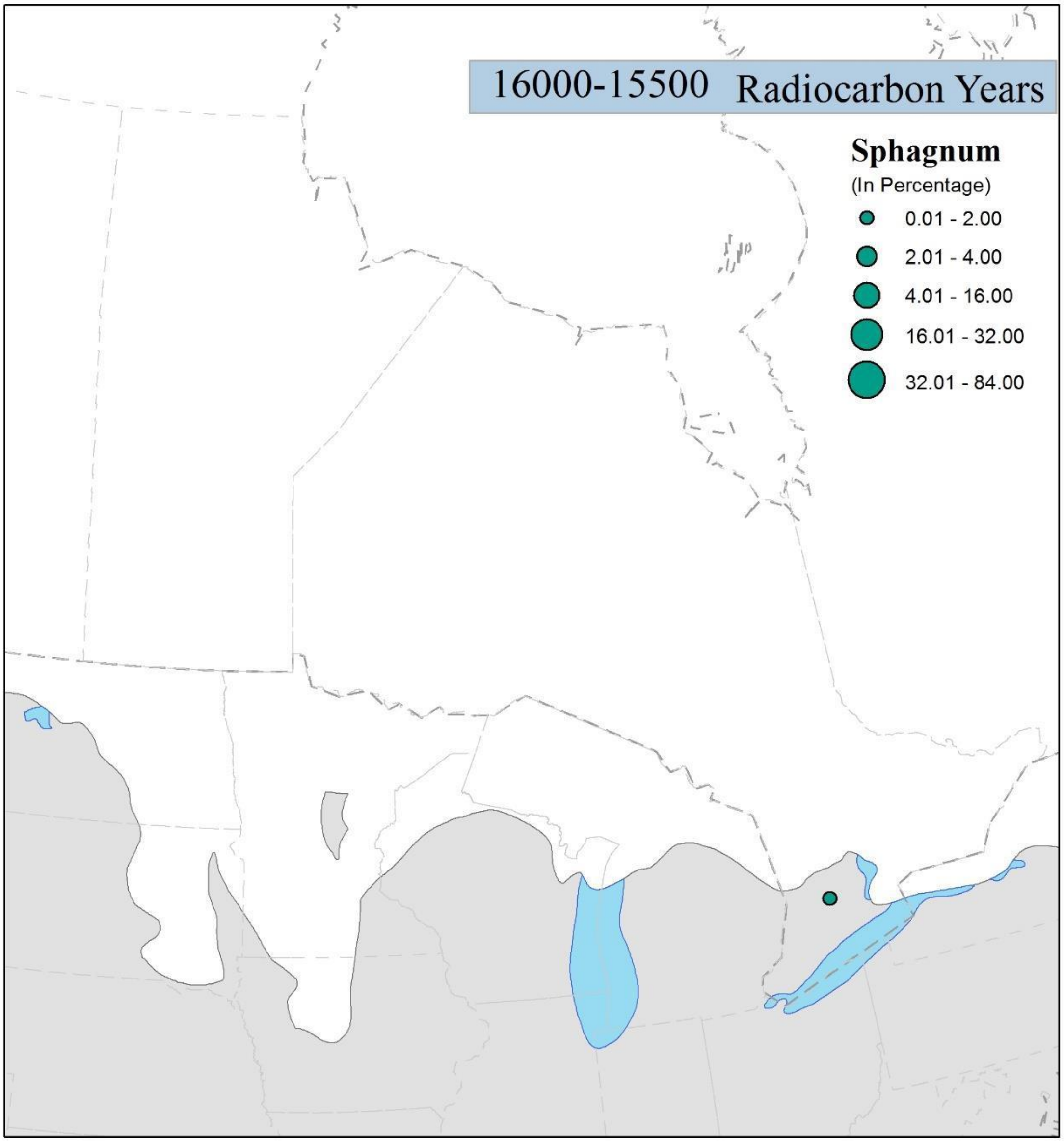

13500-13000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


14000-13500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00


15000-14500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

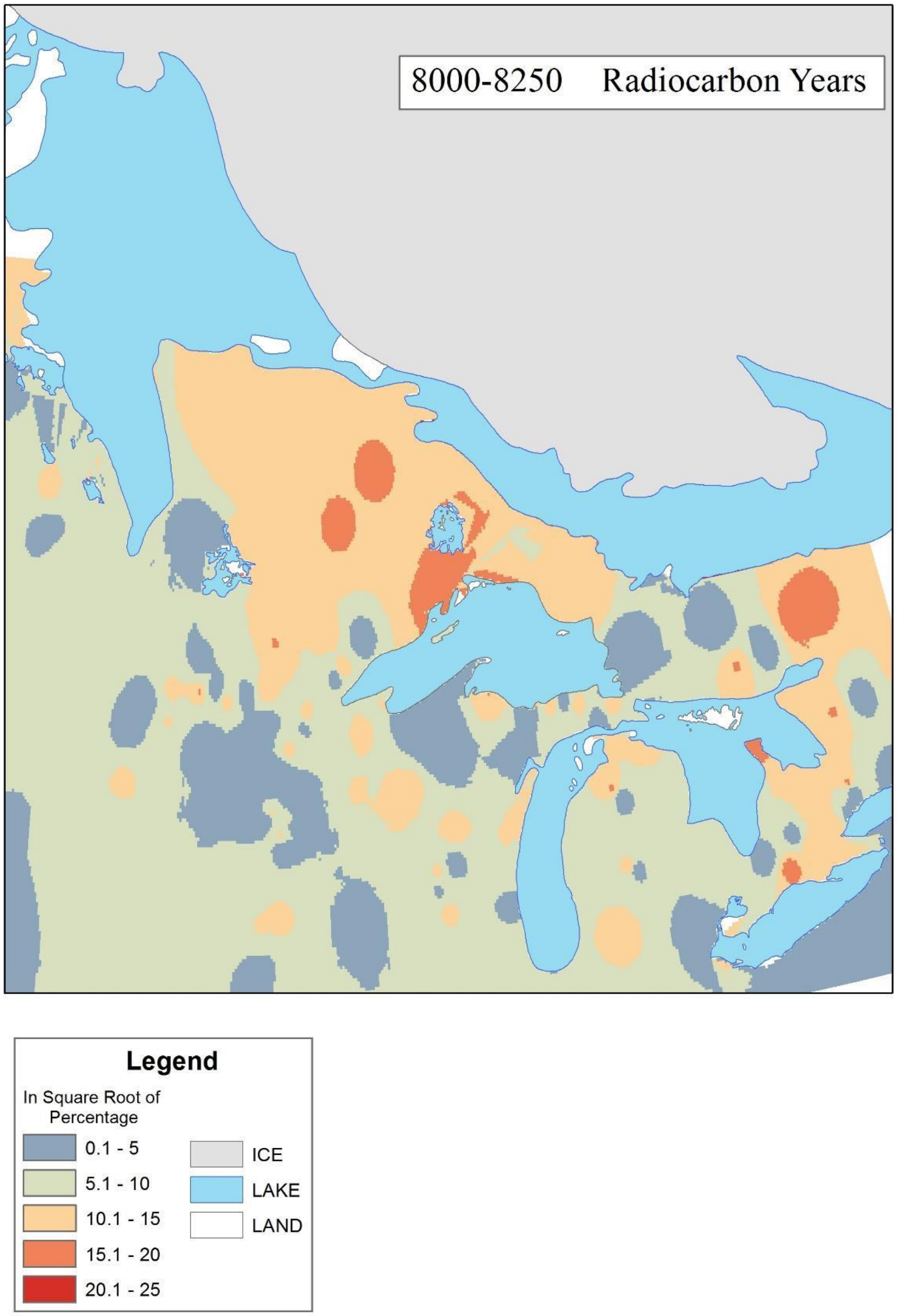

15000-14500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

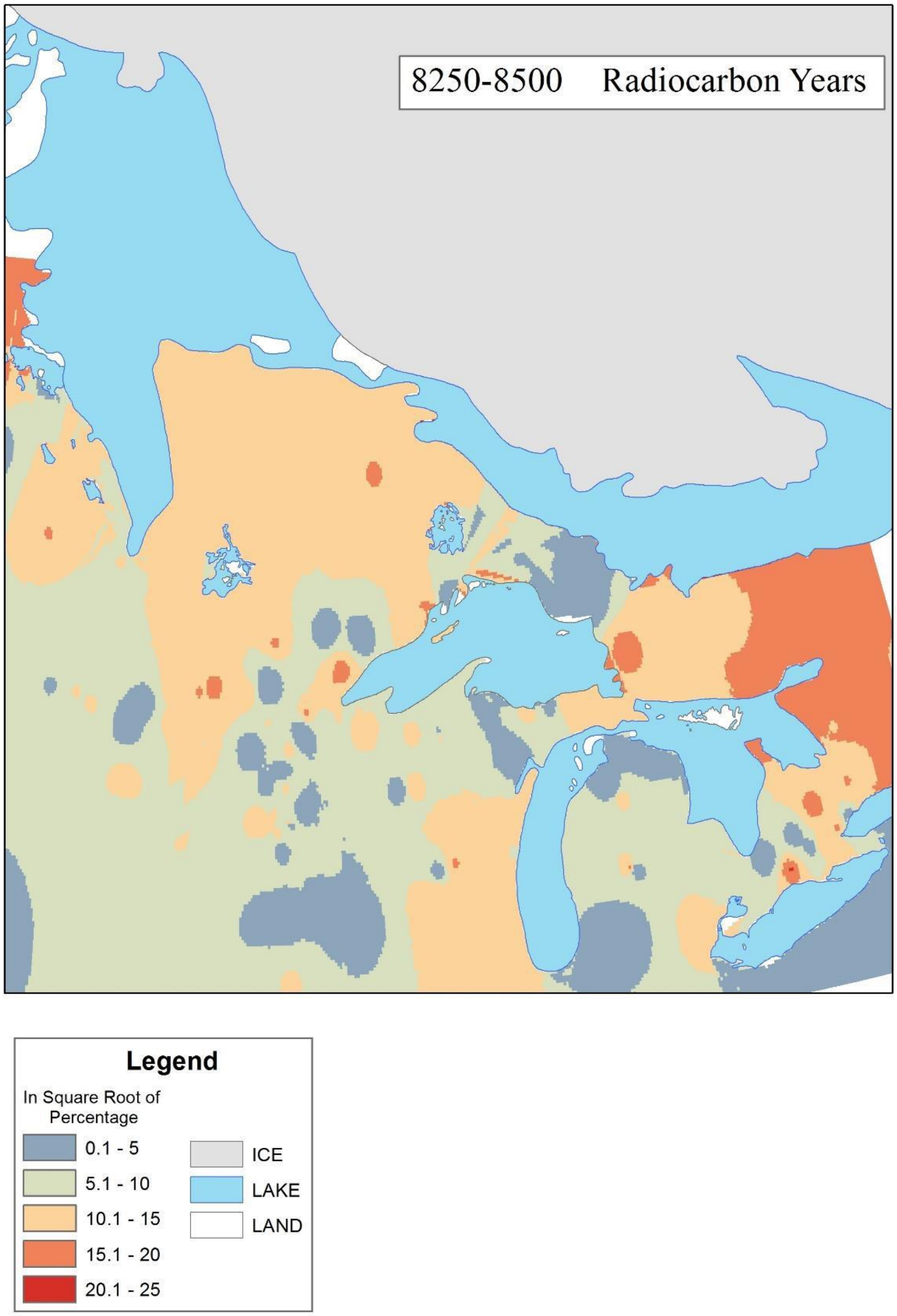

15500-15000 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

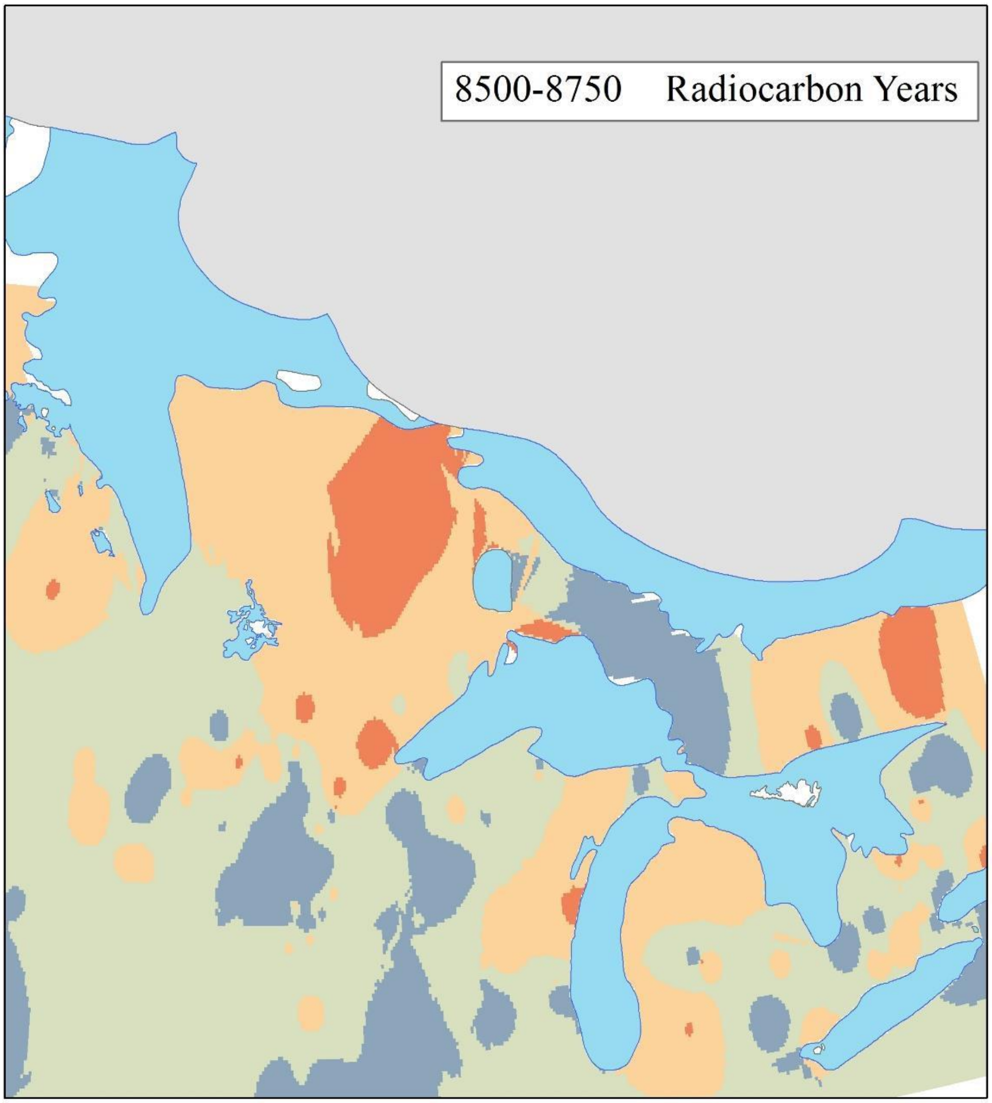

16000-15500 Radiocarbon Years
Sphagnum
(In Percentage)
0.01 - 2.00
2.01 - 4.00
4.01 - 16.00
16.01 - 32.00
32.01 - 84.00

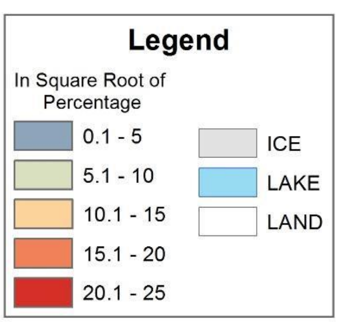
Appendix X

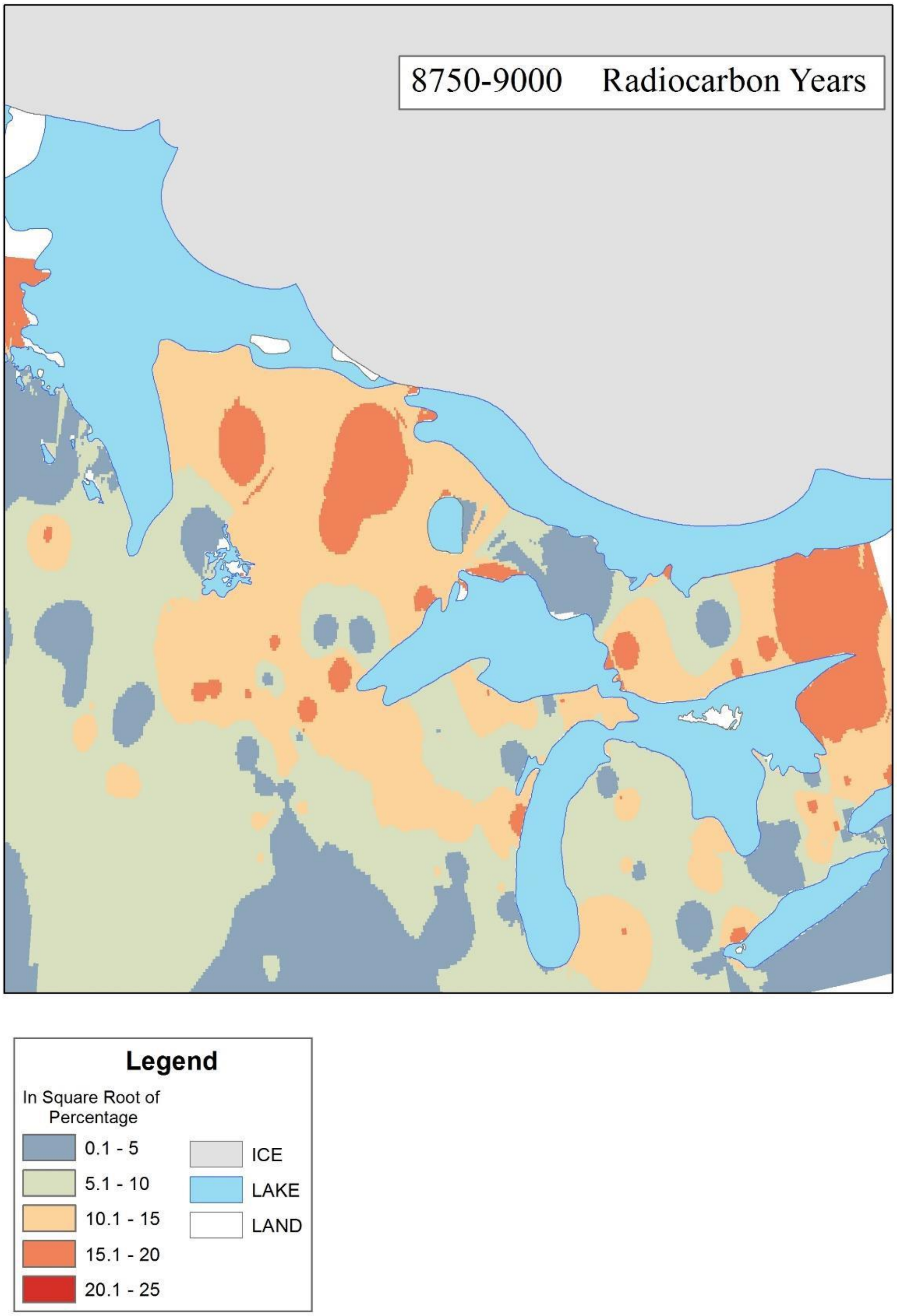
Interpolated diagrams

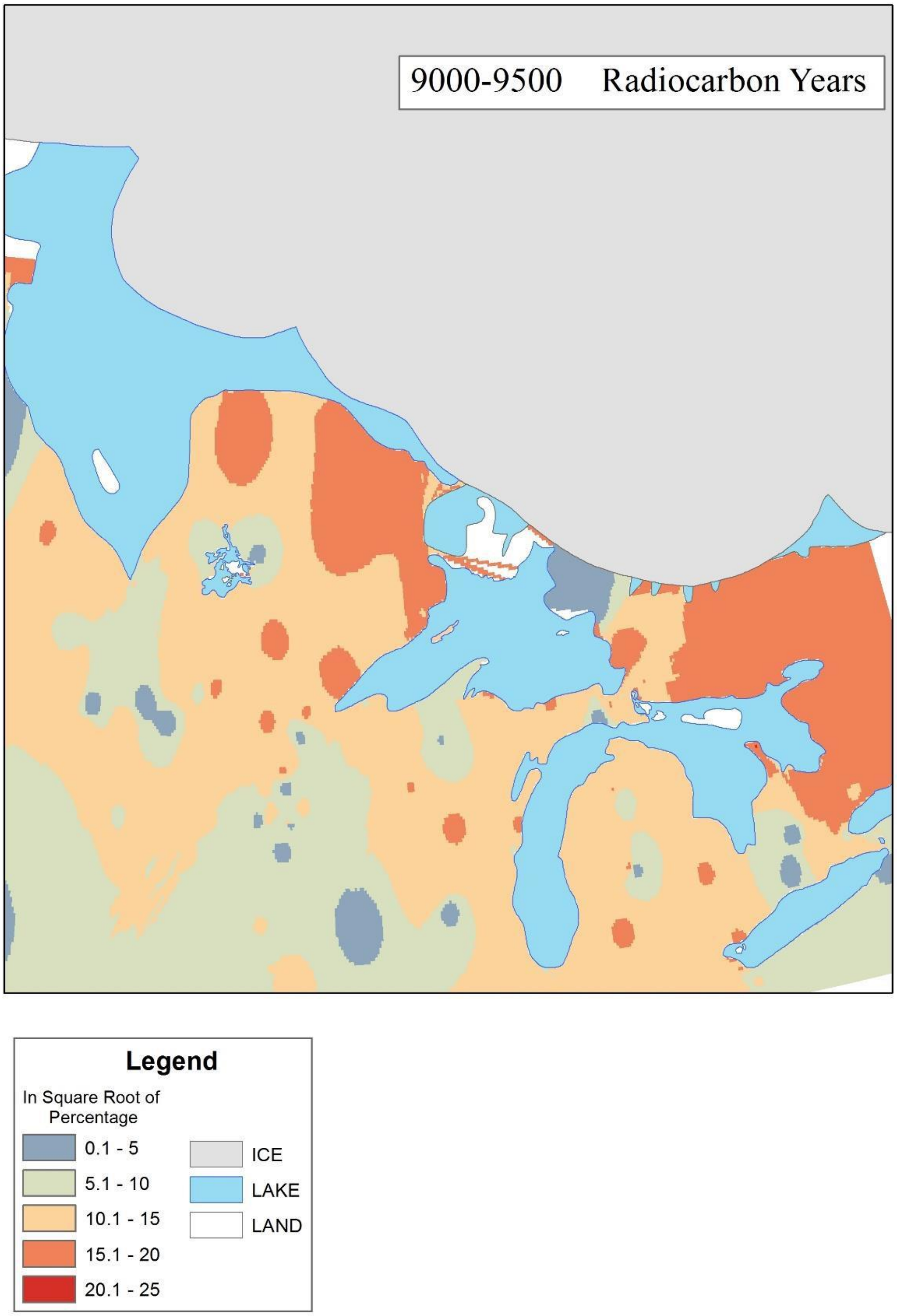

8000-8250 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

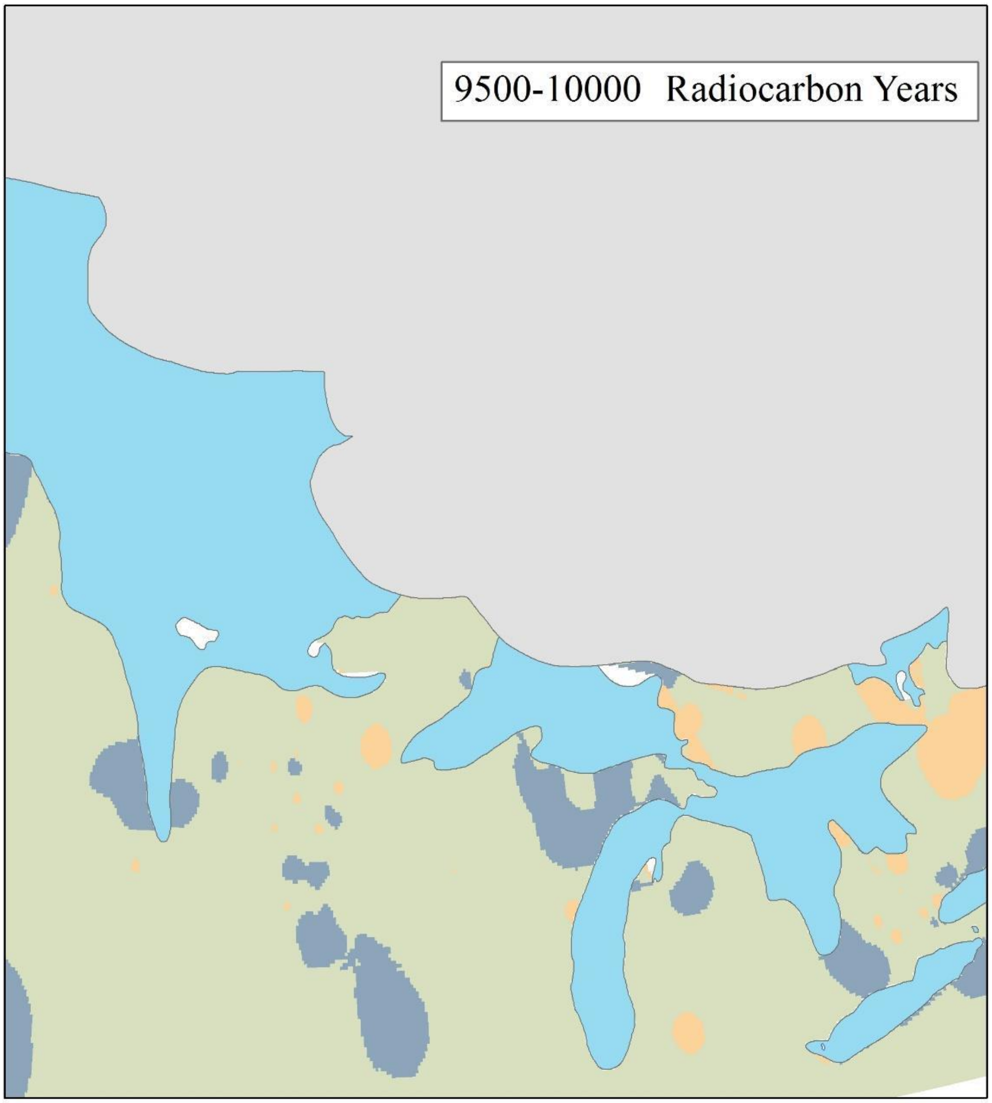

8250-8500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

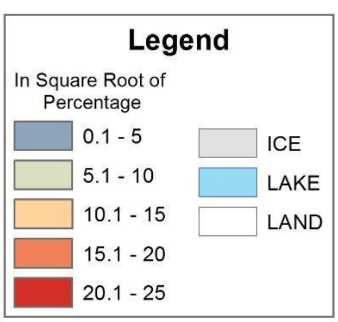

8500-8750 Radiocarbon Years

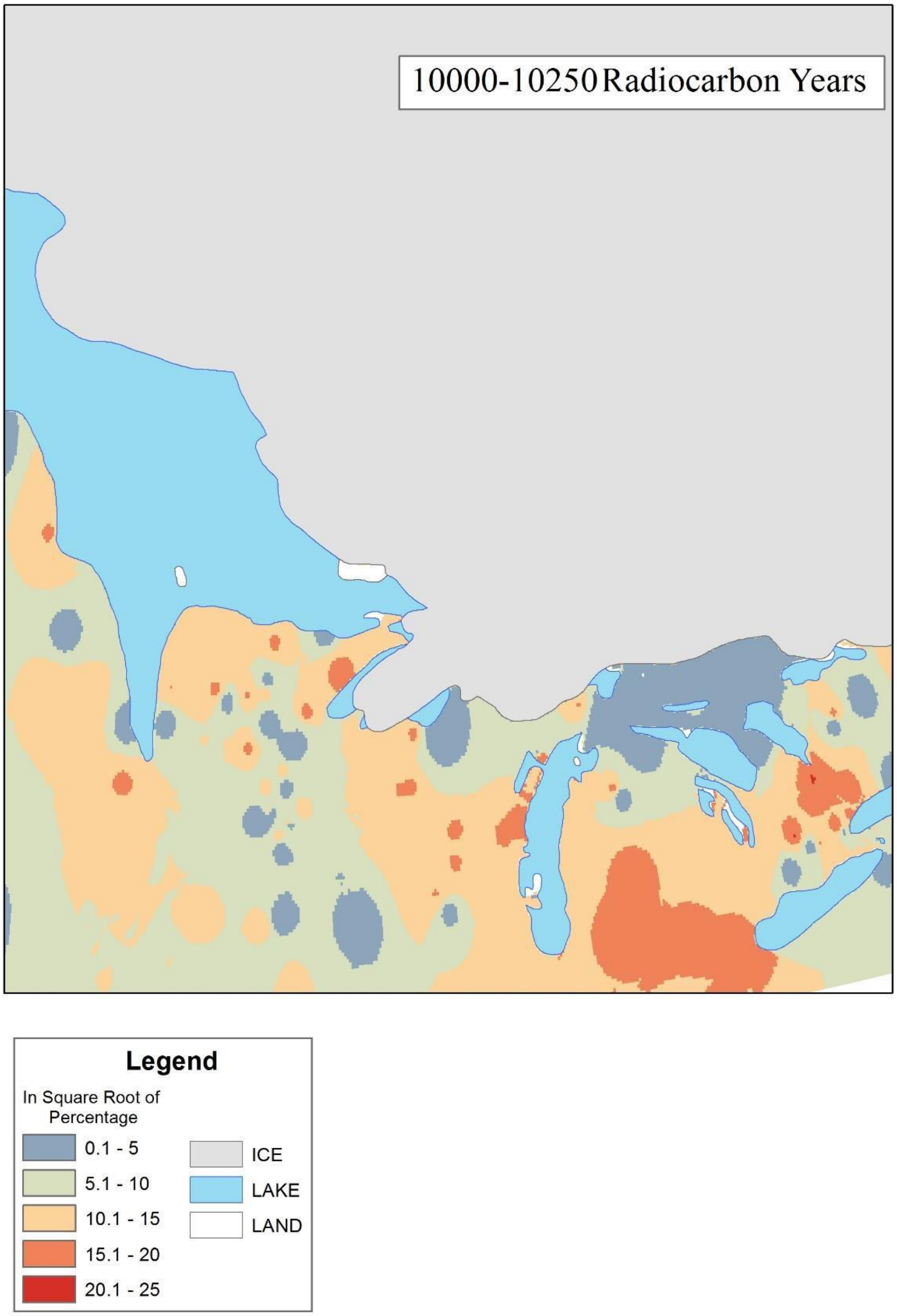

Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

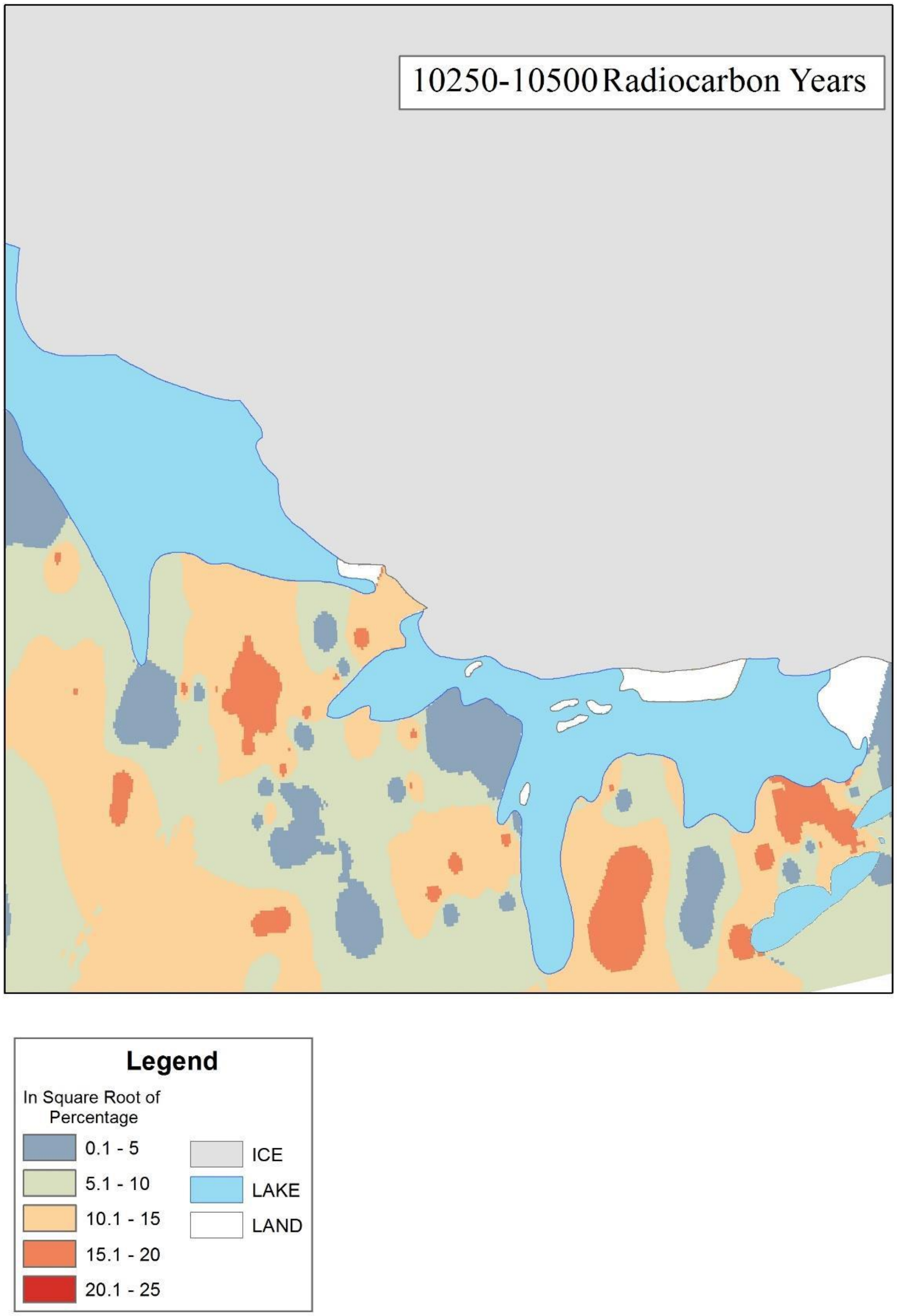

8750-9000 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

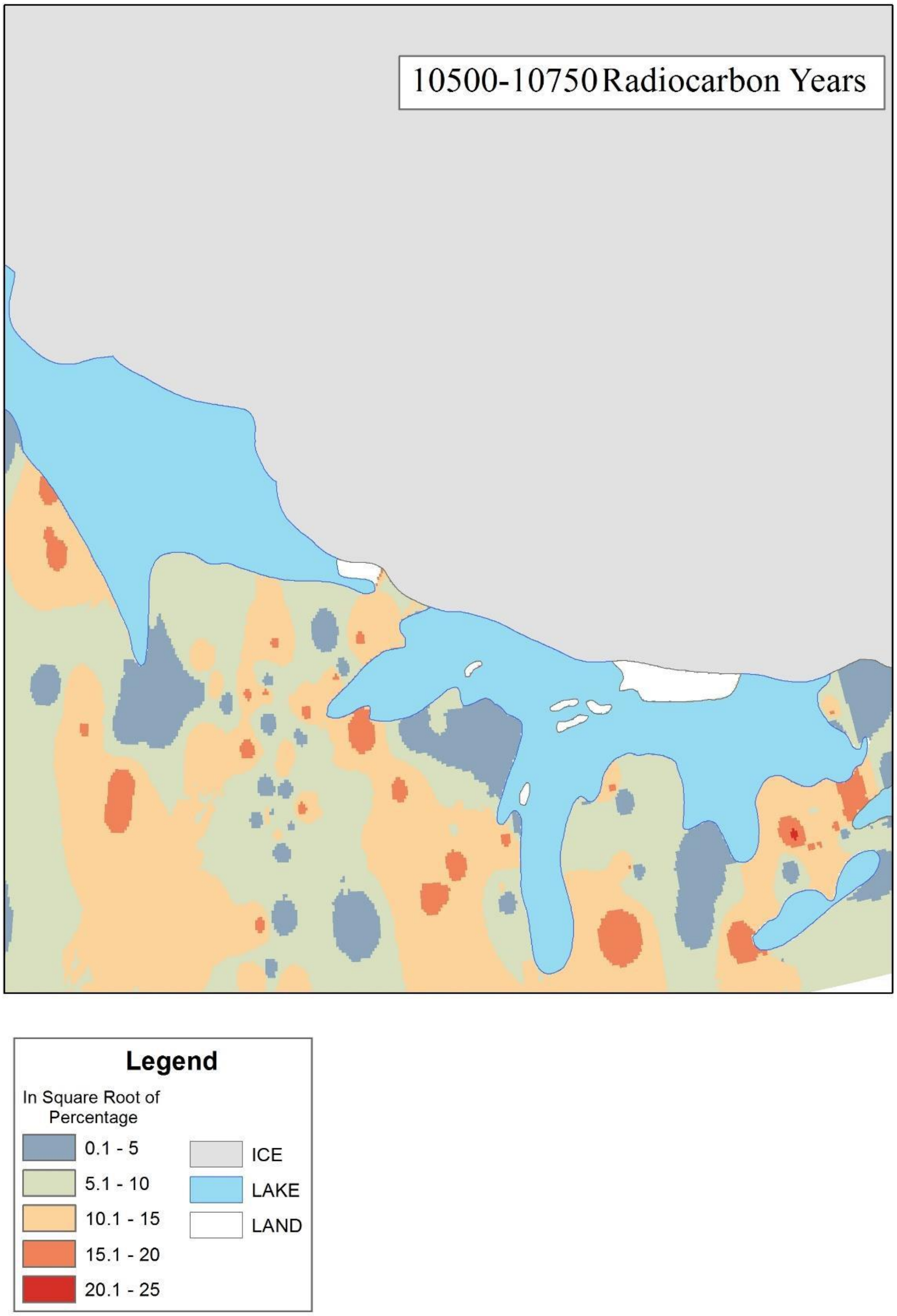

9000-9500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

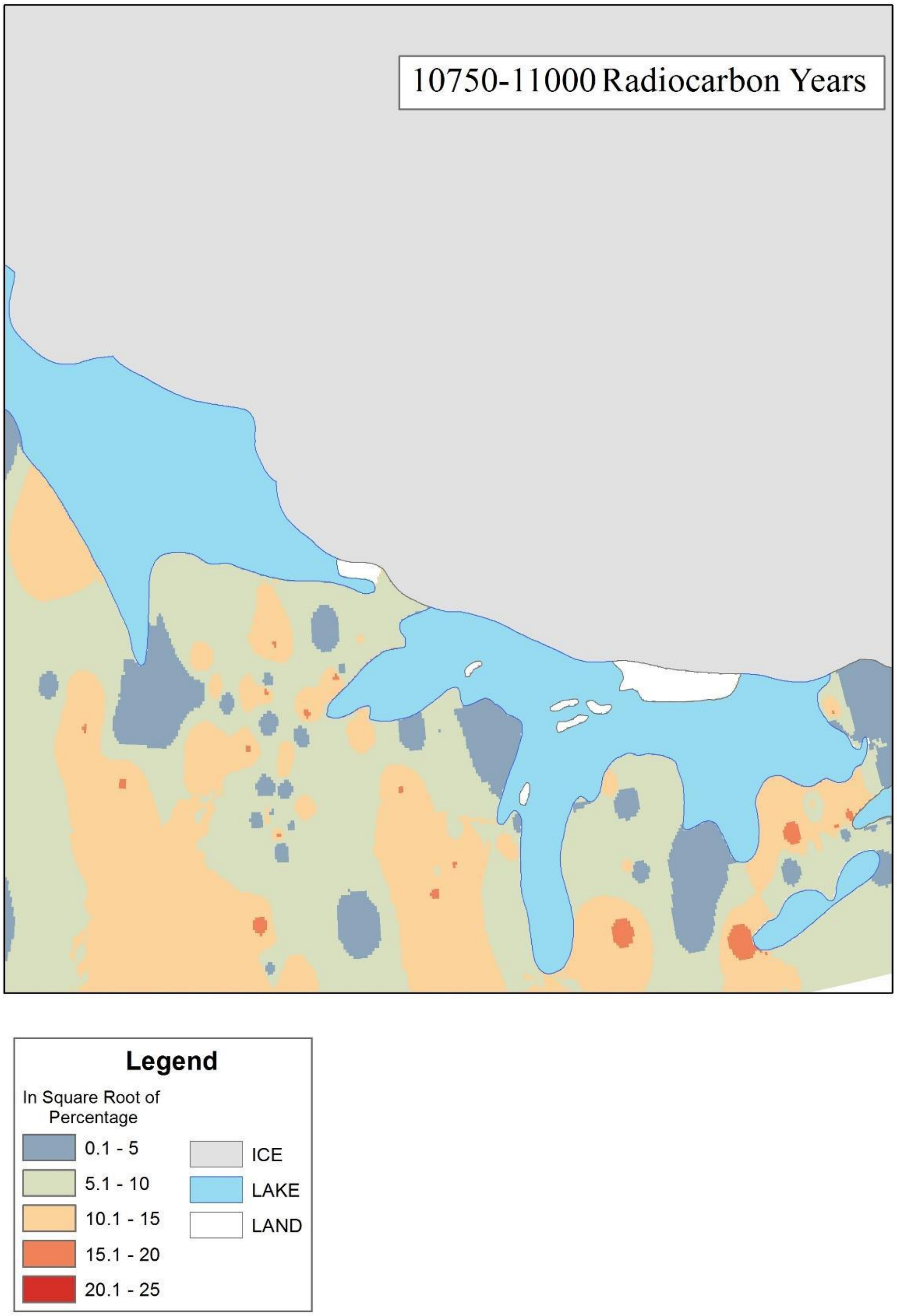

9500-10000 Radiocarbon Years

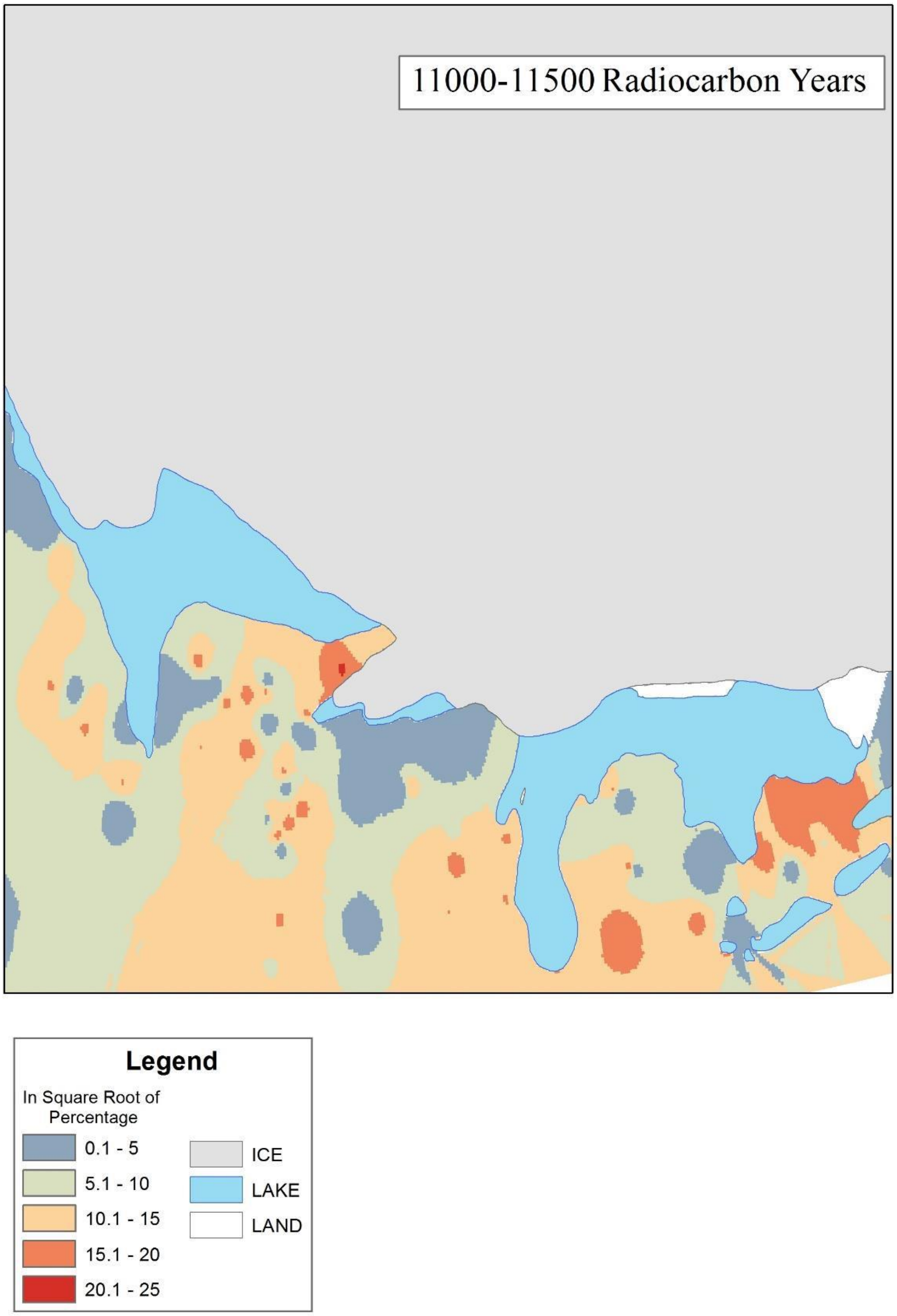

Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

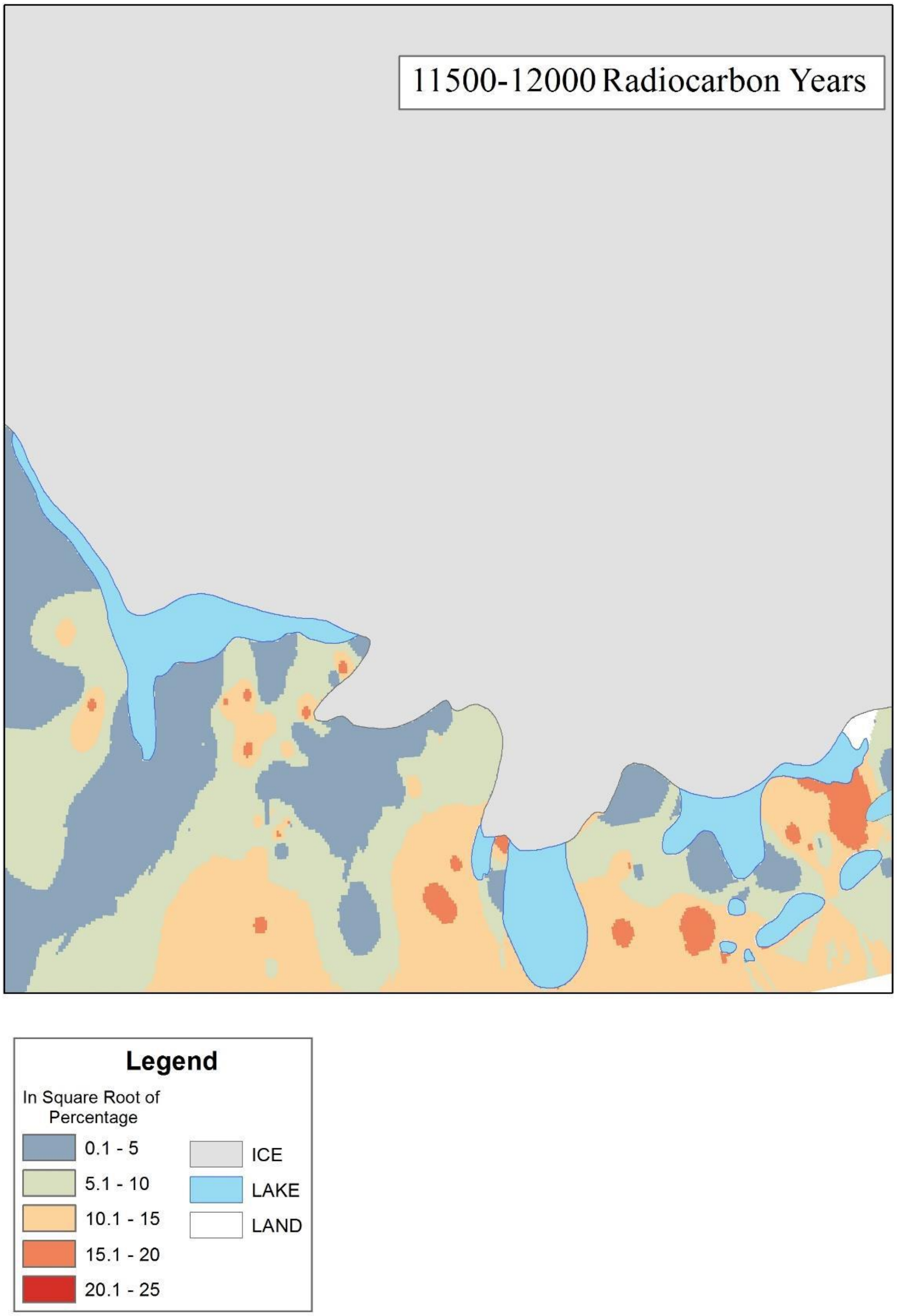

10000-10250 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

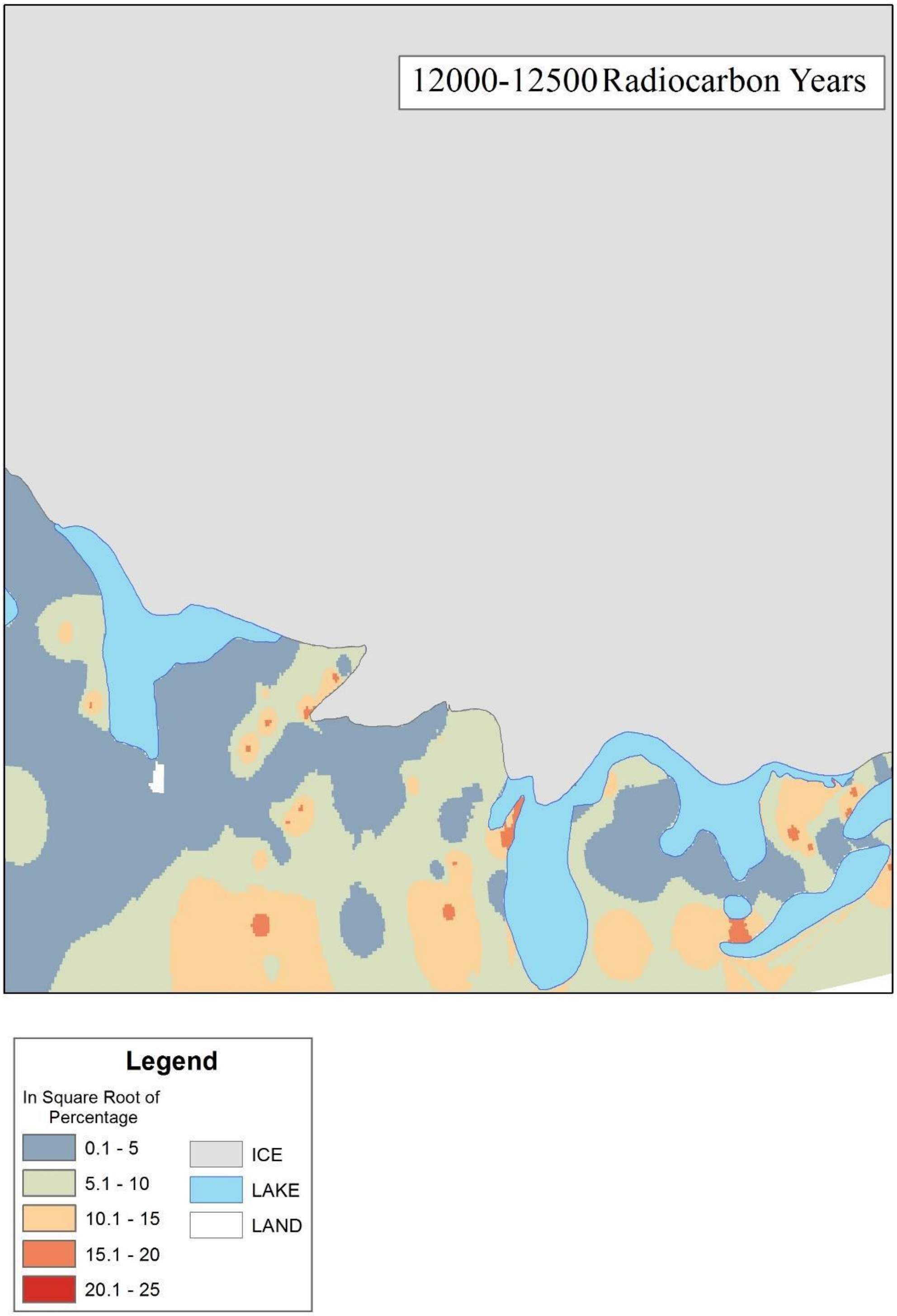

10250-10500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

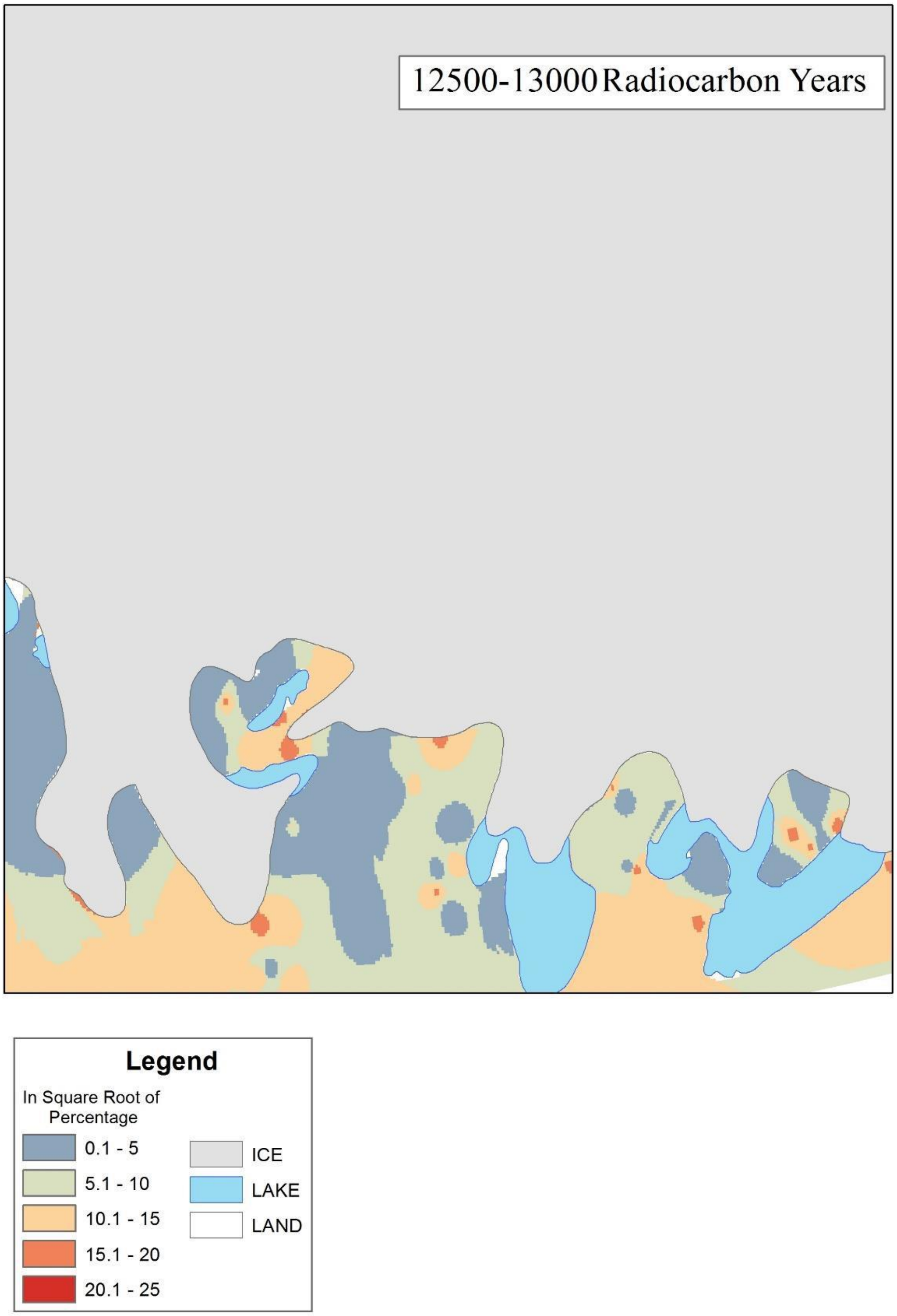

10500-10750 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

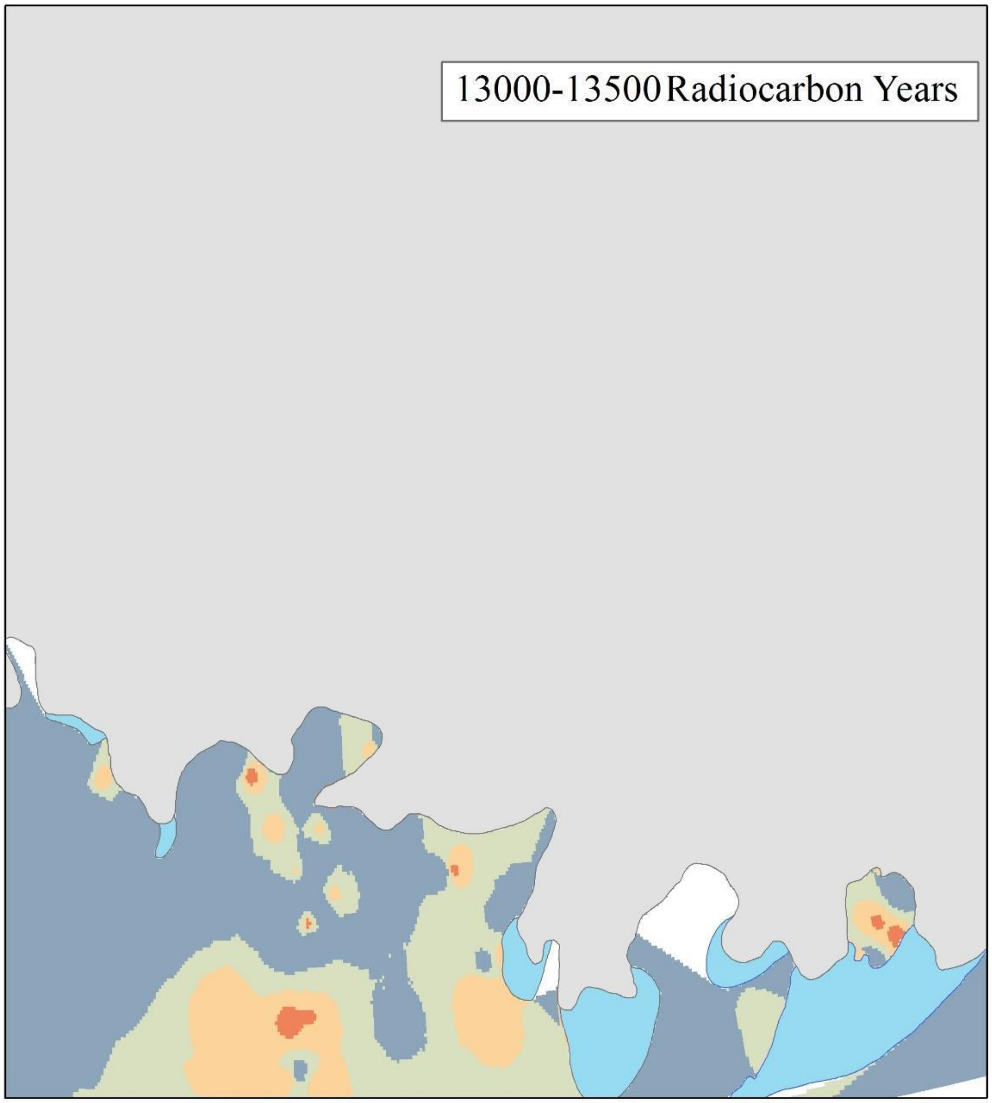

10750-11000 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

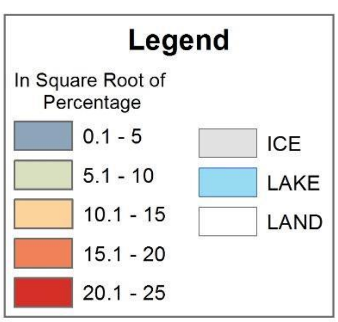

11000-11500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

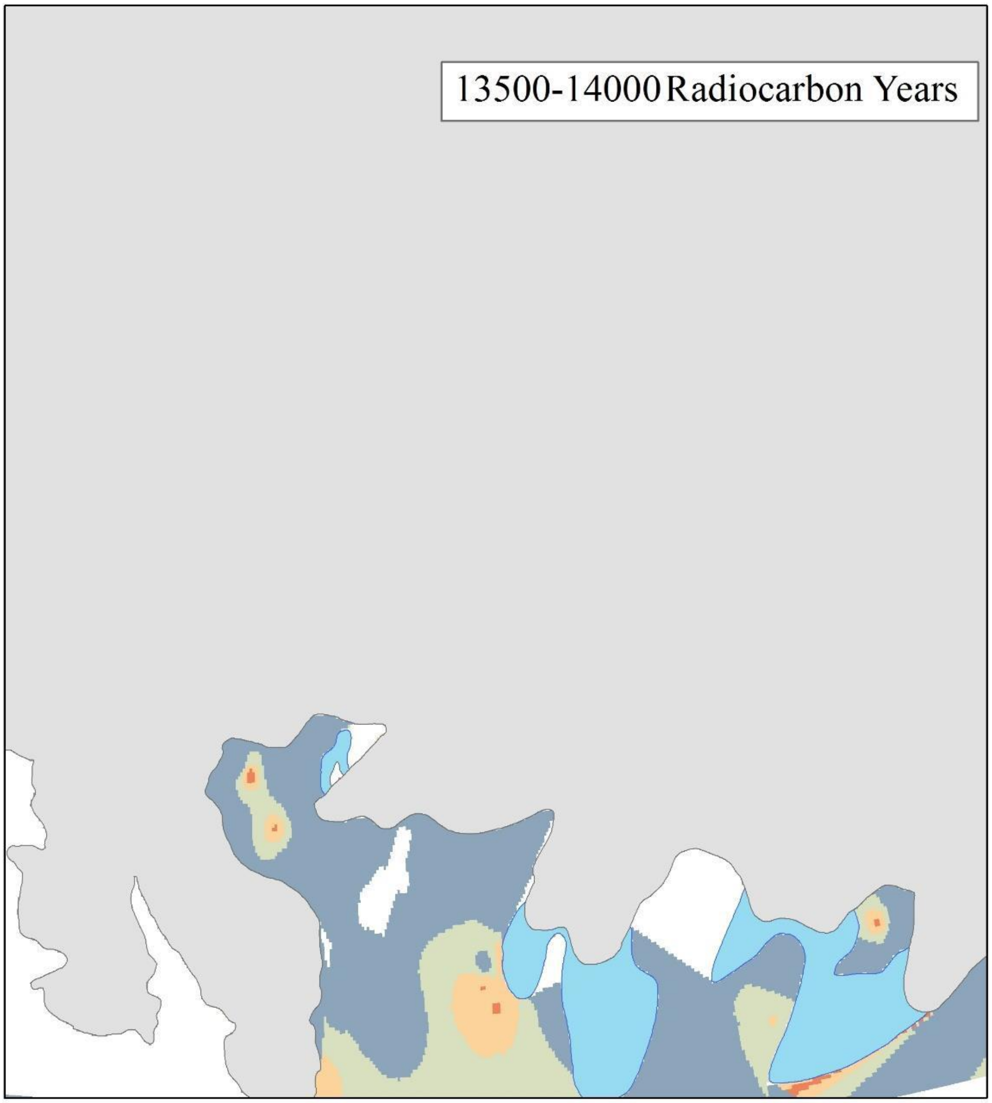

11500-12000 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

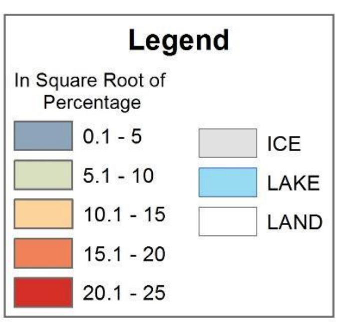

12000-12500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

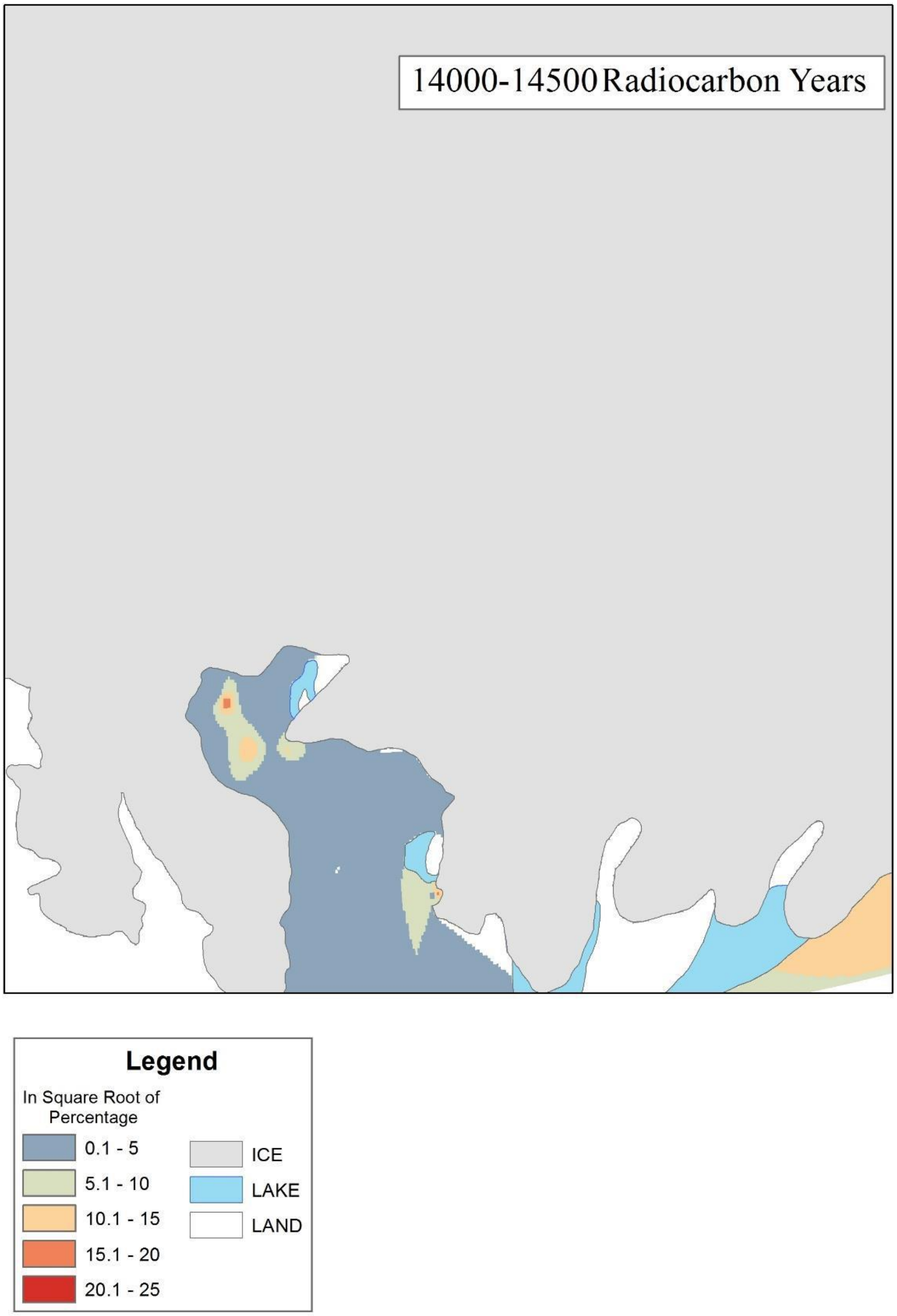

12500-13000 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

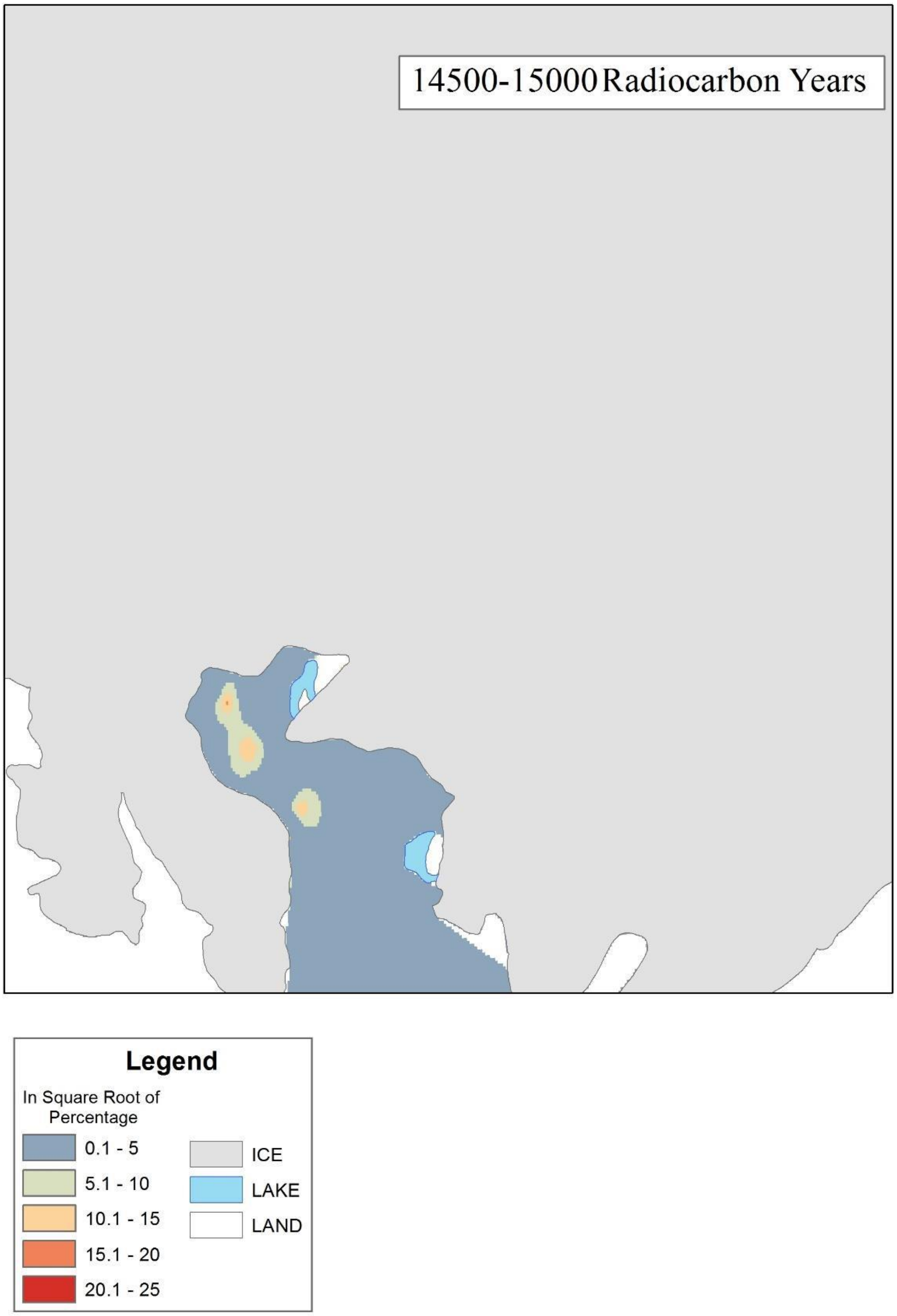

13000-13500 Radiocarbon Years


Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

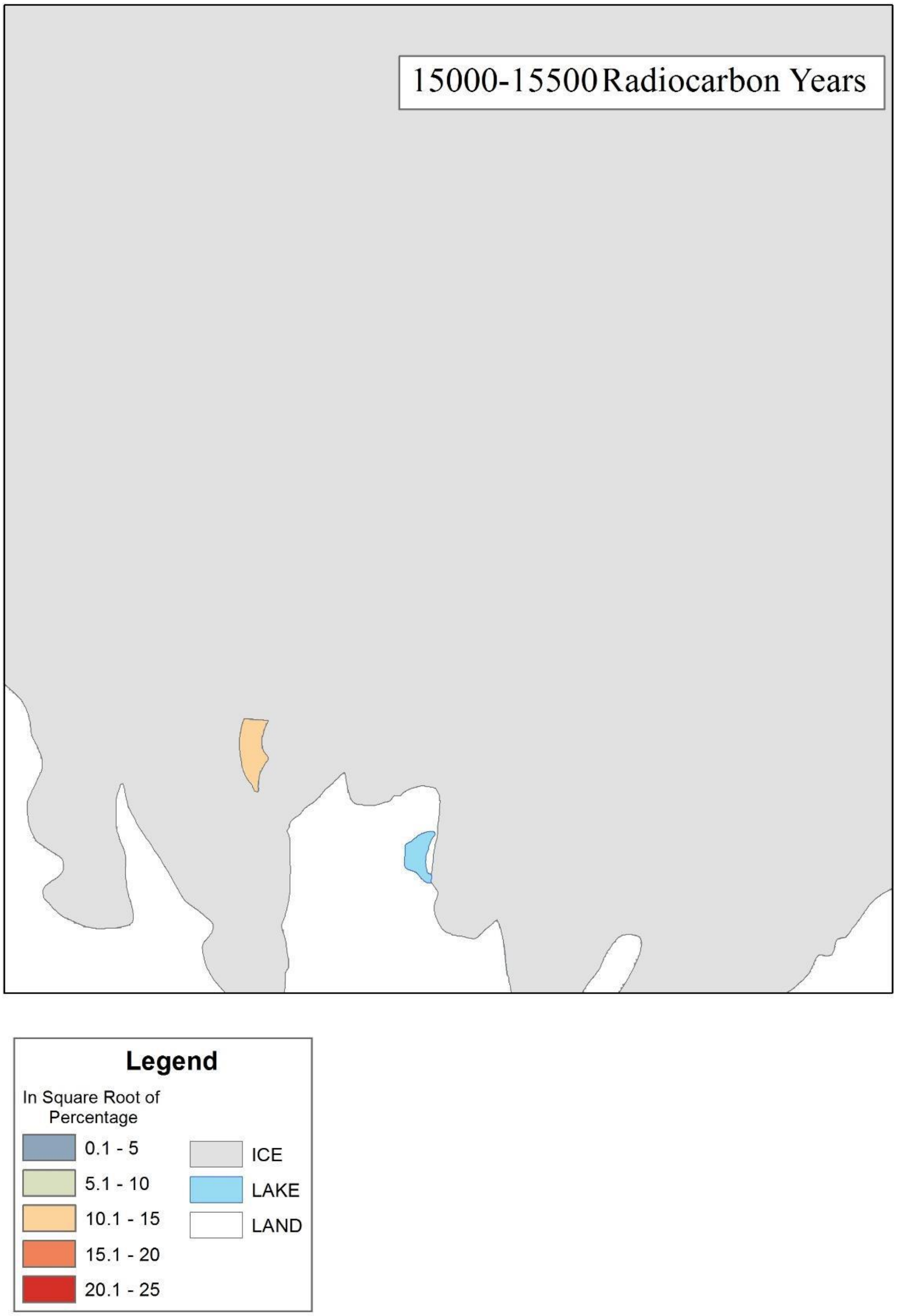

13500-14000 Radiocarbon Years

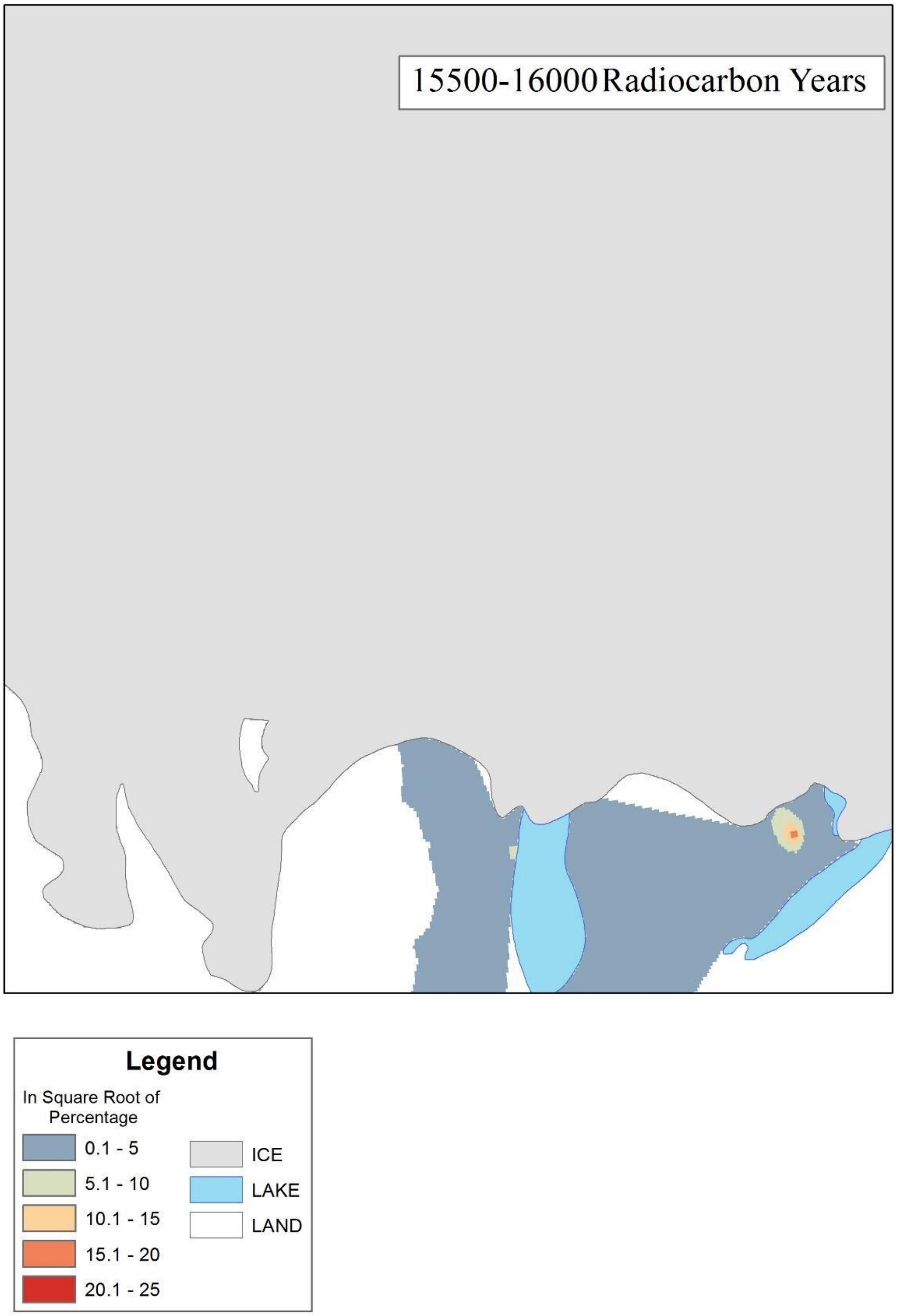

Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND


14000-14500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND



14500-15000 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND


15000-15500 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND


15500-16000 Radiocarbon Years
Legend
In Square Root of Percentage
0.1 - 5
5.1 - 10
10.1 - 15
15.1 - 20
20.1 - 25
ICE
LAKE
LAND

Appendix XI

Additional Sources Utilized

Blois, J. L., Williams, J. W., Grunn, E. C., Hacjsib , S. T., & Graham, R. W. (2011). A methodological framework for assessing and reducing temporal uncertainty in paleovegetation mapping from late-Quaternary pollen records. *Quaternary Science reviews*, 1926-1939.

Davis, M. B., Woods, K. D., Webb, S. L., & Futyma, R. P. (1986). Dispersal versus Climate: Expansion of Fagus and Tsuga into the Upper Great Lakes Region. *Vegetation*, 93-103.

Davis, M., Douglas, C., Calcote, R., & Cole, K. L. (1999). Holocene Climate in the Western Great Lakes National Parks and Lakeshores: Implicaitons for future Climate Change. *Conservation Biology*, 968-983.

Heusser, R. C., Heusser , L. E., & Peteet , D. M. (1985). Late-Quaternary climate change on the American North Pacific coast. *Nature*, 485-487.

Mangerud , A. J., Berglund, B., & Donner, J. (1974). Quaternary stratigraphy of Norden, a proposal for terminology and classification. *Boreas*, 109-128.

Theler, J. L., & Boszhardt, R. F. (2003). *Twelve Millennia: Archaeology of the Upper Mississippi River Valley.* Iowa City, IA: University of Iowa Press.

Theler, J. L., & Boszhardt, R. F. (2006). Collapse of crucial resources and culture change: A model for the woodnald to Oneota Transformation in the Upper Midwest. *American Antiquity*, 433-472.

Yu, Z., & Eicher, U. (2001). Three Amphi-Atlantic century scale cold events during the Bølling-Allerød warm period. *Géographie physique et Quaternaire 55.2*, 171-179.